The WELDING JOURNAL

JULY 1952

IN THIS ISSUE

Heat Control in Spot Welding Aluminum ... 345
Welding Gas Refrigerators ... 355
Multiple Spot and Seam Welding Specifications ... 361
Flash Control for Resistance Welding ... 365
Gas-Shielded Metal Arc Welding ... 375
Arcwelds Spot Welding ... 386
Stainless Steel Applied Usage ... 391
Fatigue Strength of Welds ... 397
Arc Welding in a Shielding Atmosphere ... 399
Plastic Behavior of Steel in Columns ... 407
Welding Handbook ... 420
Welding Index for Advertisers ... 420

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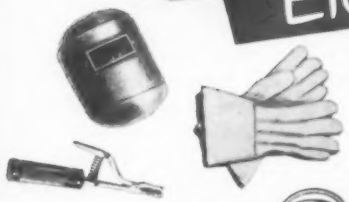

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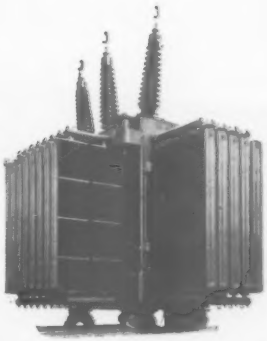

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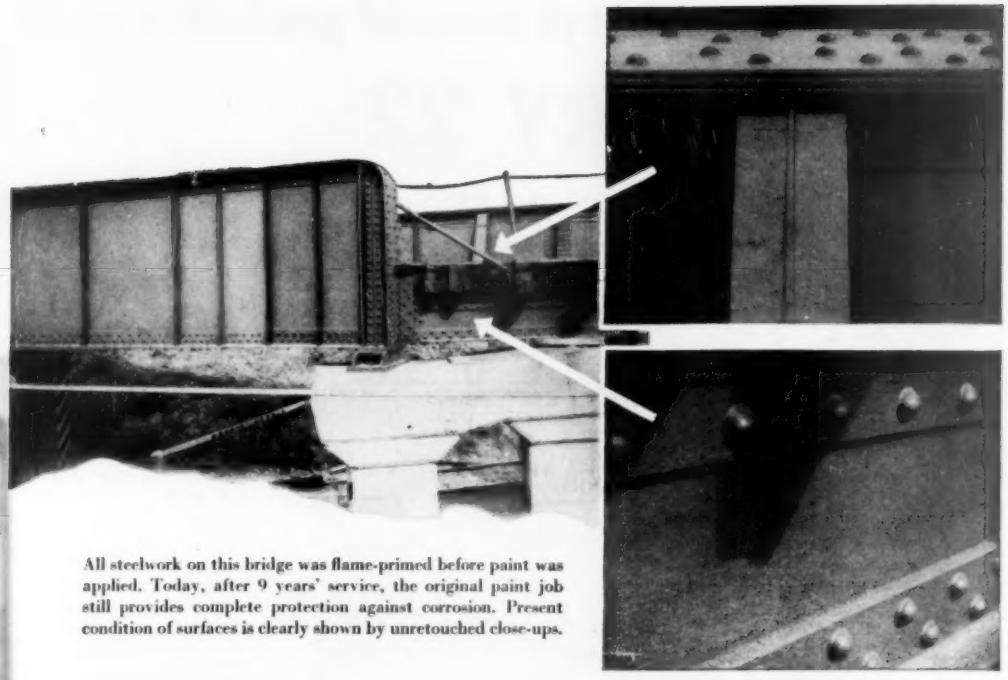

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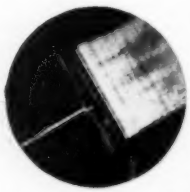

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The WELDING JOURNAL

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TECHNICAL PAPERS, ITEMS AND REPORTS

Slope Taper Control in Spot Welding 24ST Aluminum, by I. W. Johnson 549

Welding Light-Gage Tubing in Gas Refrigerators, by J. A. Ritter 552

Current Welding Literature 560

Military Aeronautical Spot- and Seam-Welding Specifications, by J. Maltz and N. E. Promisel .. 561

Process Control for Resistance Welding under Government Specifications, by Frank G. Harkins 567

Inert-Gas-Shielded Arc Consumable Electrode Welding, by H. E. Rockefeller 575

Problems and Equipment in Aircraft Spot Welding, by J. R. Fullerton 586

New Austrian Welding Standards, by Hans Melhardt 592

PRACTICAL WELDER AND DESIGNER

Fourteen Hundred Dollars Saved in Eight Hours 595

Heating with the Oxyacetylene Flame, by Earl H. Frail 596

Recording Voltmeter Checks Quality of Automatic Welds, by George A. Hatfield 600

SOCIETY AND RELATED EVENTS

Society News 602

Index to Advertisers 604

Employment Service Bulletin 605

News of the Industry 606

Personnel 616

New Products 620

New Literature 624

Section News and Events 629

List of New Members 637

Abstracts of Current Welding Patents .. 638

WELDING RESEARCH SUPPLEMENT

Stainless-Steel Applied Liners, by Helmut Thielsch 321-s

Fatigue Strength of Panels with Welded Angle Stiffeners, by R. Weck 338-s

A Survey of Arc Welding in Gaseous Atmosphere 349-s

Behavior of an Idealized Steel H Column Above the Elastic Range, by Walter H. Weiskopf 353-s

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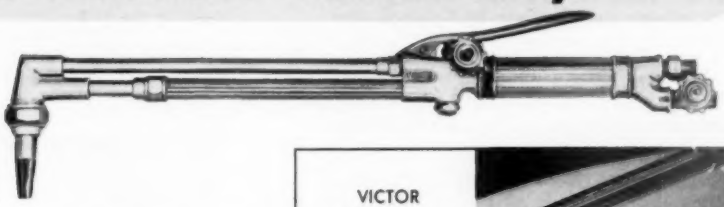

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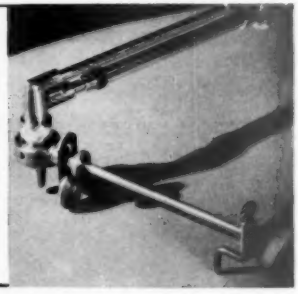

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The WELDING JOURNAL

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Slope Taper Control in Spot Welding 24ST Aluminum

The addition of taper control to the standard slope control greatly simplifies the spot welding procedure for material such as 24ST aluminum

by I. W. Johnson

INTRODUCTION AND SUMMARY

THE slope control has definitely proved its worth in various phases of spot welding. The addition of taper control to the standard slope control greatly simplifies the spot welding procedure for material such as 24ST aluminum. This paper presents and discusses data pertinent to spot welding this alloy. A summary of these data reveals the following:

1. Crack free spot welds can be made in 24ST aluminum on single-phase equipment *without forging pressure.*
2. Lower electrode force may be used than is normally recommended.
3. With the lower electrode force a substantial reduction in current demand is gained.
4. A low inertia head is not essential.
5. Equipment faults such as tip skidding becomes unimportant to the quality of the weld.

EQUIPMENT AND PROCEDURE

The slope and taper control is a supplementary device used in conjunction with standard welder control panels which utilize phase-shift heat control. In addition to the gradual increase of the current, it also permits a gradual decrease of the current after the weld has been completed. This control of the current is accomplished electronically providing precise control of the time. Figure 1 illustrates a typical current trace using such a control.

The electrodes used were Class 1 of the cadmium-silicon-copper type. A 3-in. radius was used for all recorded data. A 4-in. radius is also satisfactory. The cooling water hole was drilled to within $^1/_4$-in. of the welding surface. City water at 58° F. circulated through the electrodes at a rate of approximately 1 gpm.

The following steps were used to clean the aluminum surfaces prior to welding:

1. Alkaline cleaner at 180° F.
2. Cold water rinse.
3. 15 to 20 sec. in an acid deoxidant at 70° F.
4. Cold water rinse.
5. Hot water rinse.
6. Dry by air blast.

This procedure produces a surface resistance in the order of 50 microhms. Surface resistance was measured by clamping two pieces of work between two current-carrying electrodes at a pressure of 1000 lb. and reading the resistance on a microhmeter. The data recorded

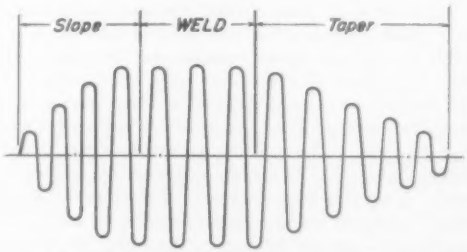

Fig. 1 Typical current trace of slope—taper control

I. W. Johnson is connected with the Welding Section of the General Electric Co., Schenectady, N. Y.

Paper was presented at a joint meeting of the AIEE-AWS-IEESD, Detroit, Mich., Apr. 16–18, 1952.

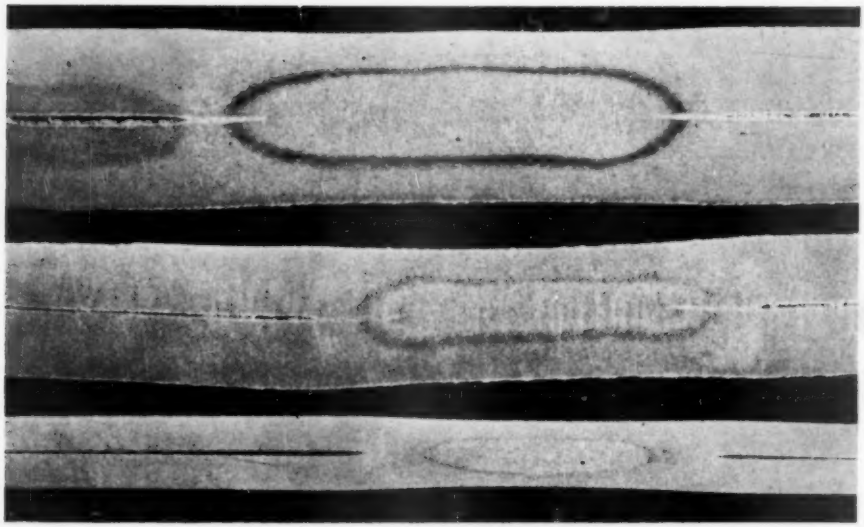

Fig. 2 Typical cross section of 24ST aluminum

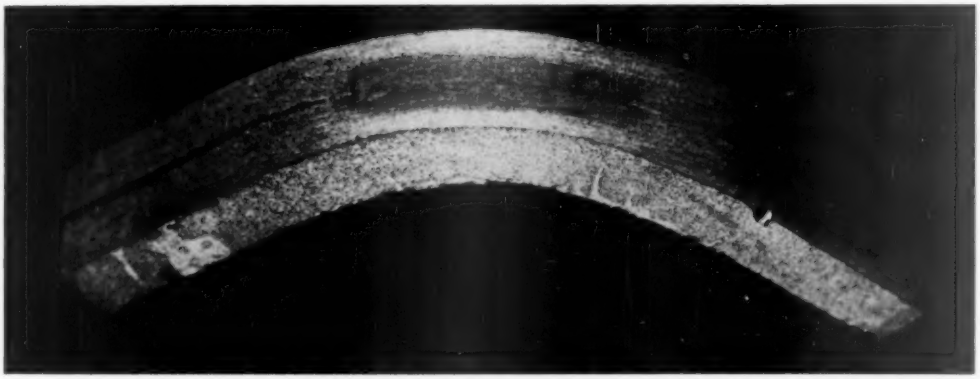

Fig. 3 Typical cross section bend test 52B1275. 8 ×

were taken on a 300-kva. machine with a head weighing 550 lb. Adjustments were made to permit a skid of the upper electrode of approximately $^{2}/_{32}$ in. The procedures thus established were also checked on a machine with a low inertia head and no electrode skid.

In all the tests MIL-W 6860 Specification was used as a guide to determine weld quality and strength. Cross section and X-ray examinations were made to determine the soundness of the spot welds. Figure 2 illustrates typical cross sections in three thicknesses. A further test that is not required by the Specification was also used. This may be referred to as the cross-section bend test. It is accomplished by cutting a piece $^{1}/_{16}$ in. wide from the center of the spot. This is etched to reveal the spot and a bend of 45 degrees is made at the center of the spot. No cracks should appear on the outside of the bend. This is an excellent test of ductility of the weld nugget and heat-affected zone. It is illustrated in Fig. 3.

RESULTS AND DISCUSSION

Welding procedures are tabulated in Table 1. These procedures produced welds that were crack free and of a strength that exceeded the requirement of MIL-W 6860. The surface appearance was smooth and without any evidence of burning or pitting. Electode cleaning was not a problem in that test run could be completed without dressing the electrodes.

The more serious defects that occur in spot welds in 24ST aluminum may be enumerated as follows:

1. Surface burning.
2. Cracks.

Table 1—Spot Welding 4ST3 Aluminum on Single Pressure, Single Phase with Slope and Taper Control

Thickness, in.	Electrode force	Current		Time cycles			Weld	
		Start	Weld	Slope	Weld	Taper	Size	Strength
0.032	1420	13,500	39,000	3	4	15	0.22	700
0.064	1750	15,000	42,000	6	6	15	0.31	1040
0.081	2270	15,000	45,000	7	10	21	0.35	1860

3. Excessive indentation.
4. Sheet separation.
5. Expulsion of metal.
6. Porosity.

Surface burning may be caused by a number of factors including surface preparation, poor water cooling of electrodes, excessive weld time, improperly cleaned electrodes. Cleaning electrodes becomes very important when work material is transferred to the electrode surface. The other factors all contribute to this transfer of material. The Slope Control tends to reduce this transfer and it has been proved on production that electrode pickup can be reduced to a minimum if normal effort is made to control the cleaning of the work material and the cooling of the electrodes. Electrode force is less critical when using slope and taper control and therefore is not a problem. Taper control eliminates the necessity of long weld time by reducing severe quenching of the weld and the subsequent thermal stress introduced in the weld zone.

It is recognized that internal or external cracks are a result of improper thermal or pressure conditions. The electrode force varies directly with the welding current. However, the electrode force that is adequate for a given welding current may not be sufficient at the start of the weld if the rate of current rise is excessive. Controlling the rate of rise with the slope control makes it possible to use lower electrode force and this in turn reduces the peak current demand. If the current is cut off abruptly at the completion of the weld very severe quenching occurs. This introduces thermal stresses in the weld and causes objectionable internal cracks. Forging pressure will minimize such cracks. This forging pressure must be applied at a very precise time with respect to the current. A gradual reduction of the current at the end of the weld reduces the severe quenching and eliminates the internal cracks without the use of forging pressure. The data indicates that at least a 13-cycle taper is necessary. The taper time increases with the thickness of the material being welded.

Excessive indentation can be attributed to excessive pressure, improper electrode contour or improper forging time. The slope control eliminates the necessity of high pressure and the taper control removes the necessity of forging pressure. If the electrodes are properly machined excessive indentation should not be a problem. Sheet separation is also caused by excessive pressures. Therefore, the lower pressures permitted when using slope control will permit work to remain in closer contact. Too long a weld time may also cause sheet separation. It has been pointed out before that long weld time is unnecessary when the taper time is properly adjusted.

Weld metal expulsion is practically eliminated when the slope time is adjusted properly. Only the most severe case of surface oxide or foreign material at the point of weld will cause expulsion when slope control is used.

Porosity in the weld structure may be caused by too rapid a current rise or inadequate forging pressure. Slope time will control the rate of current rise and the taper control makes forging unnecessary. Porosity can therefore be easily controlled.

It is not the intent to convey the thought that the slope and taper control will remove all the difficulties contributing to defective spot welds in aluminum. It is not suggested that such faults as skidding electrodes should be permitted. It is contended, however, that by normal care and attention to all factors quality spot welds in aluminum can easily be attained on production. Fabricators of aluminum can improve the quality of welds at reduced cost by the proper application of the slope and taper control.

Welding Light-Gage Tubing in Gas Refrigerators

A description of the manufacture of the refrigerating unit installed in the Servel Household Refrigerator including material, personnel and methods

by J. A. Ritter

THE Automatic Household Refrigerator of today is more or less passively accepted as a requirement of normal living, but few people realize the problems inherent in the manufacture of the product. Servel has been building their famous gas-operated refrigerator since 1927. Now they have also incorporated a kerosene and an electric type adsorption unit in their refrigerator line, which gives them an excellent coverage of the different type fuels available (Fig. 1).

Fig. 1 Servel Absorption Type Refrigerator

J. A. Ritter is Superintendent of the Unit and Water Heater Division of Servel, Inc., Evansville, Ind.

Paper was presented before the Annual Meeting of the International Acetylene Assn., Indianapolis, Ind., Mar. 31 and Apr. 1-2, 1952.

My comments will be confined in the major part to the manufacture of the refrigerating unit installed in the Servel Household Refrigerator (Fig. 2).

When we think of manufacturing we might think of the three "M's" which would stand for (1) Material:

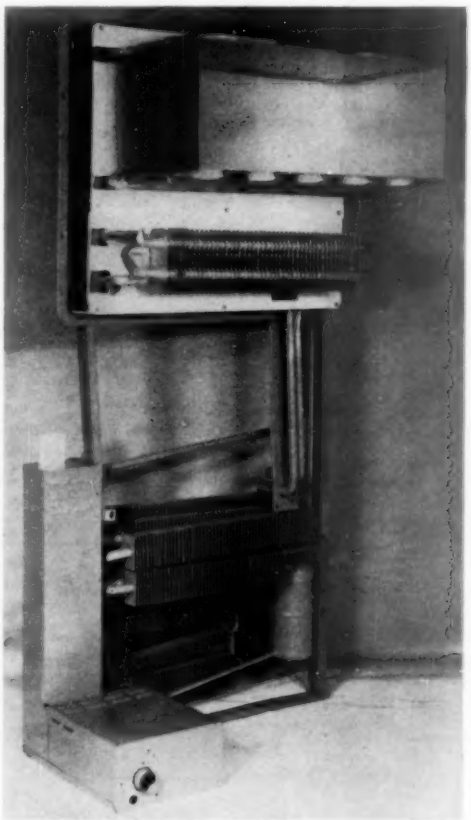

Fig. 2 Absorption refrigerating unit

(2) Men and (3) Methods. Let us first consider the item of "Material" required for the absorption type refrigerator.

Light-gage steel tubing is required of a controlled size and hardness, and conforming to S.A.E. Specification No. 1010 which is conducive to good oxyacetylene welding. The majority of our tubing is $1^1/_2$ in. in diameter, 10 gage when received, and is reduced to the various sizes required, down to a diameter as small as $^3/_8$ in. by 17 gage.

Following reduction to size, it is bright-annealed in a controlled atmosphere continuous furnace. This gives us clean tubing with a maximum tensile strength of about 55,000 psi.

The tubing must undergo very severe bending, therefore, Rockwell hardness is held to approximately 55 to 65 "B" scale.

We carry a large quantity of steel tubing stored ahead of the fabricating department. As the various sizes are needed, they are processed through the different pieces of cutting equipment, and washed to remove oil and dirt. The tubes are bent and fabricated into the shapes necessary for the manufacture of the unit.

Figure 3 is an exploded view of most of the elements that make up the working parts of a unit. A look at this is convincing that welding must be employed as a means of assembly. At this point you might well ask—why use oxyacetylene welding instead of soldering or brazing? The answer is that the finished joint must be able to withstand 1000 psi. air pressure safety test and not be attacked by the corrosive properties of the ammonia refrigerant. This automatically rules out any type of soft solder from the strength angle alone. Brazing would require a copper bearing material which is incompatible with the ammonia charge in the unit.

We are extremely careful to see that all tubing is free from surface copper before it is assembled, as contaminated tubing would shorten the life of the refrigerator. It has been found that even a tack weld made with brazing rod will leak due to the alloying of the copper with the steel. Since the unit must withstand the operating pressure of the ammonia refrigerant for years, without leaking, we have found that we must confine our joining of the assemblies to welding with iron welding rod.

Almost $1^1/_2$ lb. of welding rod is used on each of the

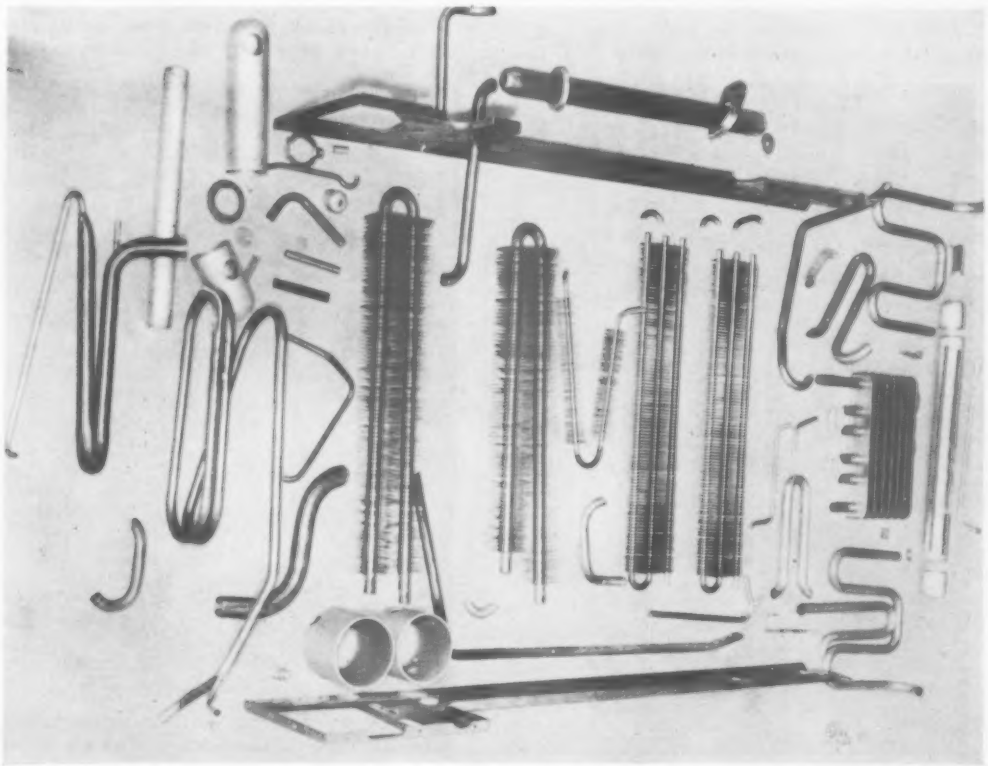

Fig. 3 Exposed view of the elements that make up the working parts of a Servel refrigerating unit

Fig. 4 Sludge and water from acetylene generators are pumped into overhead tanks. When water has been drained off, sludge is hauled away

large units. The analysis of this welding rod falls in the AMERICAN WELDING SOCIETY'S SPECIFICATION No. 7. We use $^{3}/_{32}$-in. diameter rod except in a few special cases. We have found that chemical analysis alone does not define the suitable rod for our use. It must be free of all inclusions, gas bubbles and scale if we are to get a leakproof weld. The percentage of leaks found at our leak test goes up immediately if a shipment of inferior rod is used.

Servel furnishes acetylene for welding through more than $1^{1}/_{2}$ miles of pipes from a generator room in a

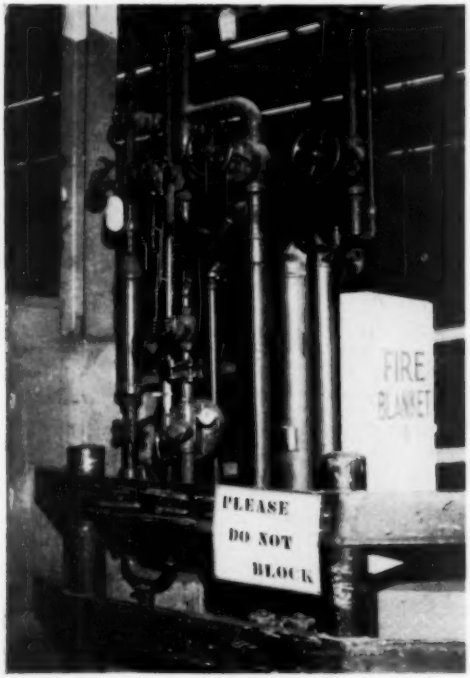

Fig. 5 Master regulator keeps oxygen at constant pressure of 28 psi.

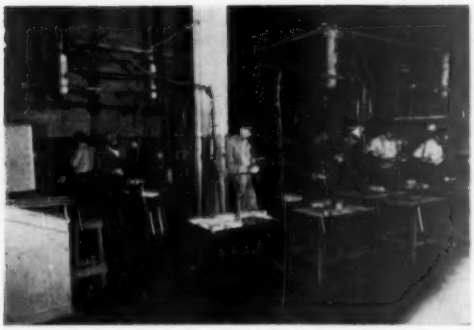

Fig. 6 Men of proper qualifications are trained for period of four to five weeks in plant's welding school

windowless building constructed especially for the generation of acetylene.

The building has many safety features incorporated in its design, and it complies with the most stringent insurance codes. All the electric wiring is explosion-proof. Wood or nonsparking material is used throughout the building.

The storage room for carbide is 9 in. higher than the generator room, which forestalls the possibility of water coming in contact with the carbide.

The generator room proper contains six medium pressure acetylene generators of the following specifi-

Fig. 7 Oxy-acetylene welding small sub-assembly in fixture

cations: Each has a capacity of 500 lb. per charge, a water capacity of 500 gal., and will generate 1000 cu. ft. of acetylene gas per hour at a maximum generator pressure of 15 psi. Positive safety devices make sure that this maximum pressure is never exceeded and that a line pressure of about 12 psi. is maintained.

Each generator forms 113 cu. ft. of sludge per hour. This sludge is drained into an outside sump where automatic pumps force the sludge and water into overhead tanks of 200 cu. ft. capacity each as shown in Fig. 4. The sludge is allowed to settle and is drained into Dempster dumster trucks which haul it away from the plant for disposal.

Oxygen is received in Evansville by special tank car in liquid form, these cars being in effect very large thermos bottles. At Servel it is transferred to receiving tanks and, by means of a converter, is evaporated from liquid to gas and piped throughout the plant to the welding stations.

In the departments before the point of usage the acetylene is piped through a master hydraulic and pressure regulator which maintains the pressure in the department at about 3½ psi.

In Fig. 5 you also see the master regulator for the oxygen flowing through the pipe lines to the welding stations. Oxygen is kept at a constant 28 lb. pressure. This careful control of gas pressure is important to the welder who does not have to adjust blowpipe valves, and even more important it helps maintain a uniform flame that in most work is slightly oxidizing.

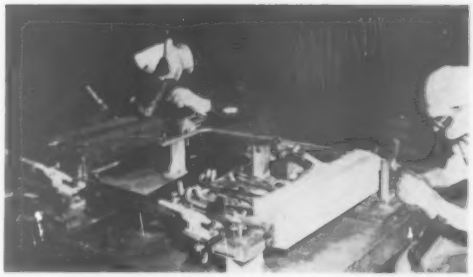

Fig. 8 Parts and sub-assemblies for the condenser and the absorber are located and clamped into place in this fixture

Most of the blowpipes are standard, using tips ranging in size from No. 6 to No. 12 according to the welding job. However, in some cases where close quarters or

Fig. 9 Unit has been transferred from assembly jig to conveyor line, where the pressure-tight welds are made

restrictions of space presents a problem, we use special blowpipes with the end bent to an angle to form the tip.

The old style pilot lighter has been replaced by the clean but sure-fire electrical igniter. An overhead angle iron frame at each welding station is wired to a low voltage 12-v. transformer. All the welder need do to light his torch is snap on the acetylene and oxygen, and lay the tip of the torch across a grounded steel plate and touch the angle iron to strike a spark. This is quick, economical and eliminates what once was quite a problem.

Next let us consider the second "M," which stands for "Men" who are a very necessary part of the manufacturing process. We are constantly faced with the problem of having an adequate supply of trained welders to meet the demands of a varying manufacturing schedule. We have found it impossible to hire men from the open labor pool of the required skill needed for our type of work.

Therefore, we must fall back on men who have previously worked as oxyacetylene welders at Servel, or we must train them for this job.

Figure 6 is a view of our plant welding school in which men of proper qualifications are trained for a period of four to five weeks. We try to get trainees under 30, with good eyesight and in top physical condition. A man advances from very simple types of welding on scrap plate to more complicated types such as horizontal, vertical and even overhead welding as he shows his ability to progress. A student is constantly under the watchful eye of several instructors and supervisors who handle his training. When he has completed his preliminary work in the school he is transferred to a welding job in the assembly department and allowed to work for approximately one week to learn the technique of welding upon a moving conveyor or in a fixed jig.

After completion of his training period he is placed on an assigned job in the manufacturing operation. It would be fortunate indeed for us if this training would make an accomplished oxyacetylene welder, but we have found that it takes months of actual work on the line before he is capable of doing a good job of welding, holding leaks to a minimum.

Each welder on production is usually assigned to a particular weld. It is easy to keep a record of his work, as any leaks are recorded by leak testers by numerical identification. There are 85 pressure welds and 60 tack welds on this unit.

Our welding department is probably the largest single department at Servel and one of the largest in the country devoted almost entirely to oxyacetylene welding of light-gage steel tubes.

The unit is assembled from smaller subassemblie

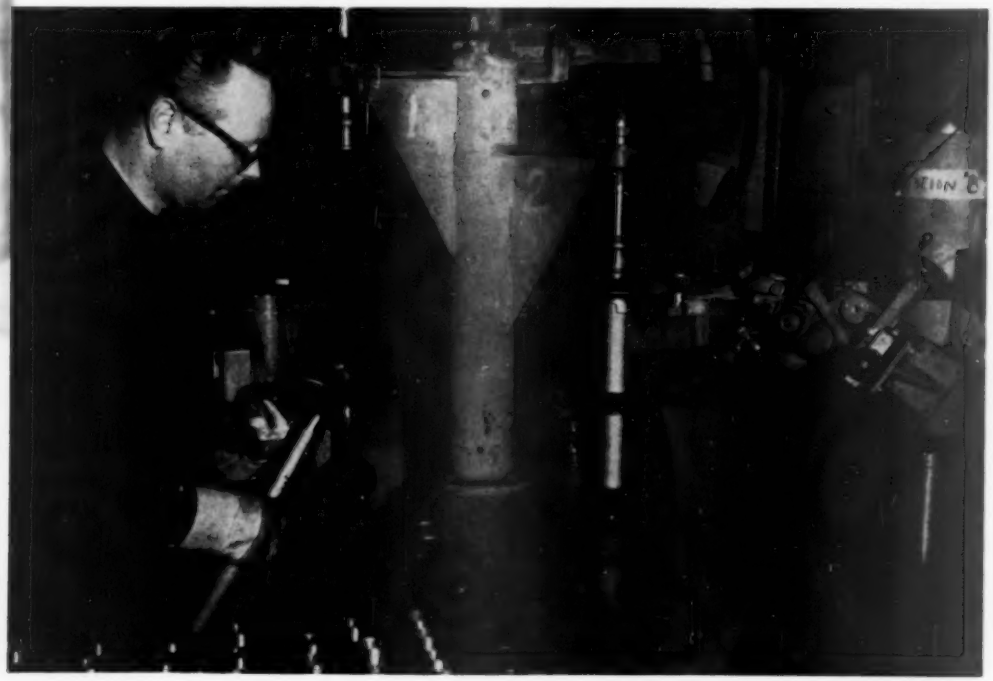

Fig. 10 Submerged-arc welds cut labor cost. Here is three-station machine that welds the generator assembly

which are built in fixtures located in separate lines that feed into the main jigs. In Fig. 7 the welder is joining a small pump tube to the pump chamber of the unit boiler system.

Parts and subassemblies for the condenser and absorber are located and clamped in place in the large fixture illustrated in Fig. 8. Notice the heavy cast-iron base and sturdy locators with holding clamps which maintain the correct relationship between the different assemblies.

After the unit is transferred from the main jigs to the moving conveyor, the pressure tight welds are completed.

A sufficient number of operators are assigned to weld on the assembly line so that each can complete his task easily in the allotted time as the unit moves along.

The conveyor hangers are made on a swivel as shown in Fig. 9, and the unit can be turned to almost any position to make the weld accessible for the best welding condition. Movement of the conveyor must be steady and constant, and must not be at too great speed to allow the man to accomplish his welding task.

Through design of the unit and careful study by process engineers, and with the help of outside vendors, we have been able to incorporate in the unit several joints made by submerged arc welding.

The generator assembly is welded by the submerged arc process illustrated in Fig. 10. A total of three welds is made on this machine which requires two cycles to make a complete assembly. This enables us to use one operator with a minimum of training to replace several highly skilled oxyacetylene welders who had previously been doing the job. Perhaps I should mention

Fig. 12 Two-station absorber pot submerged arc welding machine

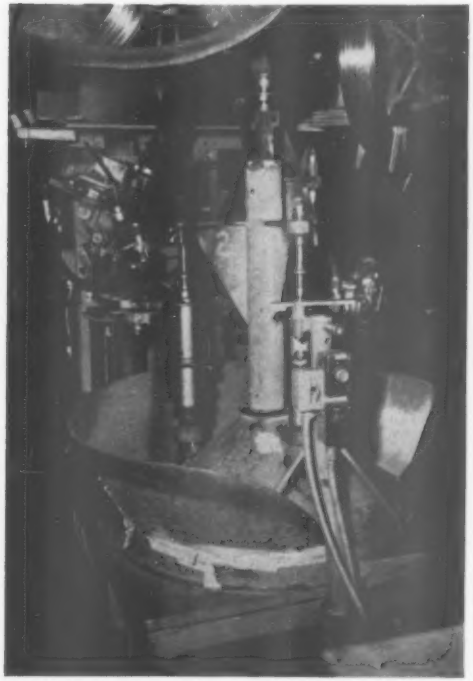

Fig. 11 This shows the loading station of the 3-station machine and one of the end welds being made in first welding station

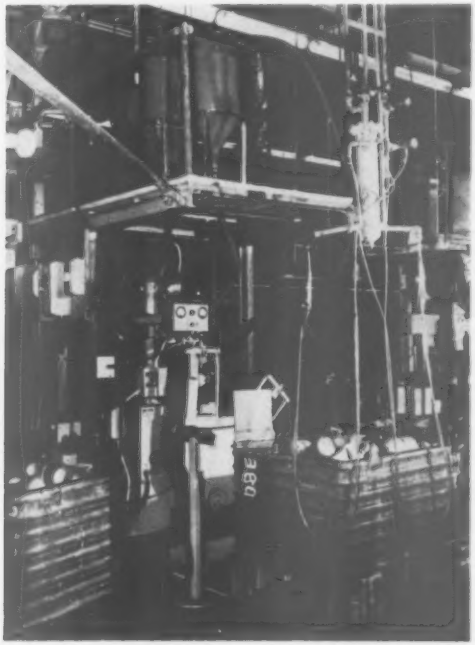

Fig. 13 Complete flux setup on submerged arc welding machine

that in spite of advances in automatic arc welding, such displaced welding personnel is always moved to another oxyacetylene welding operation. The demand for skilled oxyacetylene welders has always been greater than the supply of trained man power.

Figure 11 shows the loading station of the 3-station machine and one of the end welds being made in first welding station.

Formerly the charging valve housing was welded to the absorber pot by the oxyacetylene torch method.

The housing is an automatic screw machine part. In order to get the desired free machining qualities we use steel of S.A.E. No. 1019. This is not the best type material for oxyacetylene welding and, as a result, we had a bad leak record at this joint.

A 2-station machine was designed to submerge arc weld this housing to the absorber pot. We use No. 29 rod, $^{3}/_{32}$-in. in diameter, No. 50 flux and have the machine set at 350 amp. This is a small part and the weld is made quickly, running about 4 or 5 sec. per job. The machine shown in Fig. 12 has replaced four skilled welders, now available for other jobs, with one semiskilled operator, and has practically eliminated leaks at this joint.

Figure 13 shows the complete setup including flux hoppers overhead.

The Engineering Department, in the design of the new unit, found that they had to have the vaporizing chamber and inner pipe joined together lengthwise, very intimately, in order to have the proper heat transfer. It was practically impossible to do this by oxyacetylene welding as the finished part had to be straight, without any warpage.

The machine shown in Fig. 14 was developed to do the operation and we now lay a 10-in. long bead on either side with the submerged arc process.

This weld was difficult to perfect as the arc would burn through one or the other of the tubes. It was only after a formed piece of $^{1}/_{8}$-in. welding rod was laid between the two tubes that the weld became a production possibility.

When the part leaves this machine it is plug-gaged for straightness. Drawing limits allow only 0.020 variation in 10 in. of length. Even with careful control of submerged arc welding, these limits were difficult to maintain.

A machine was designed to straighten this assembly, using a 4-flame water-cooled head traveling on a side

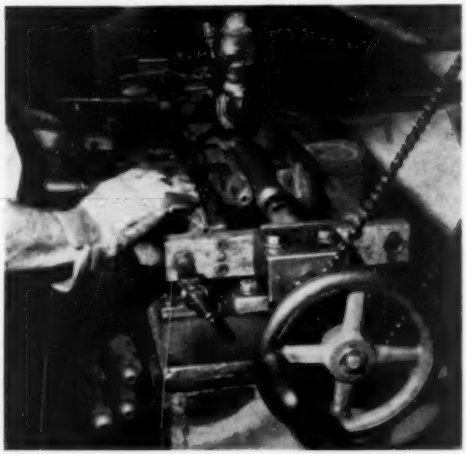

Fig. 14 Machine lays 10-inch beads to join the vaporizing chamber and the inner pipe together lengthwise

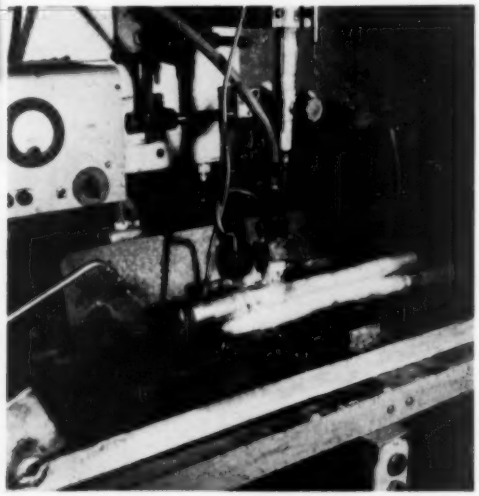

Fig. 15 Welded assemblies are straightened to required tolerances by means of a flame-straightening setup

Fig. 16 Metal spraying evaporator refrigerating unit

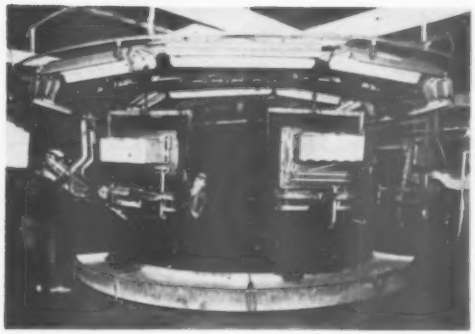

Fig. 17 Testing Station. Here the completed units are given their successive leak tests with air at 850 psi.

beam carriage at 50 in. per minute. This torch heats the tube on one side. Immediately after the assembly is brought to temperature it is chilled by a stream of cold water to remove any warpage caused by the submerged arc welding process. Once started, the machine travels through its operations and shuts off automatically. The traveling head is returned to starting point manually and the new part located in the holding fixture. With the setup shown in Fig. 15 we are able to straighten practically all of the assemblies to required straightness, thereby eliminating a costly machining operation.

The welded portion of the evaporator and gas heat exchanger system is hot-dip galvanized. Steel tubing is bonded to the aluminum sheet of the evaporator box. The galvanized assembly is joined to the evaporator assembly by welding.

Almost all of this tubing is colder than the surrounding air when the refrigerator is in operation and might be subject to condensation of moisture. To assure long life of the unit, the raw welded joints must be protected.

After sandblast to remove scale, pure zinc is applied with a metalizing gun.

Oxygen and acetylene from our regular lines are used for this metalizing operation. Acetylene is used at full line pressure, being piped around the master regulator.

Figure 16 shows a man working in a well-ventilated booth but wearing a hood supplied with fresh air to avoid metal spray that might rebound in his face.

Our welding must be not only strong, but leakproof. All refrigerator units are tested at 1000 lb. air pressure for rupture. Then they are given successive leak tests at 850 lb. The unit is charged with high-pressure air and a soap solution is placed on the various welded joints to see if they leak as illustrated in Fig. 17.

The best and more experienced welders are used as repair welders and are expected to clean up and close those leaks which are found in the soap test procedure. After the unit has been completely assembled and tested, it is then charged with the re-

Fig. 18 Refrigerating final assembly line

quired amount of refrigerant mixture and sent to the capacity test where a final leak test is also given. Since we use an ammonia solution as our refrigerant, we are able to make a very rigid leak test by wrapping the welds with a piece of moistened paper previously treated with a chemical that reacts in the presence of ammonia. Any leak, regardless of how small, will allow the ammonia vapor to seep through and turn the white paper to a reddish pink at the point of the leak.

Any units that leak or fail to pass the required capacity test have the solution discharged, and are steamed and dried. The leak or welded joint which might be plugged is repaired or replaced, and the unit is recharged and sent to the capacity test for check.

The finished unit is transported to the Cabinet Division by conveyor as shown in Fig. 18, and there is assembled into a cabinet to make a complete refrigerator.

Each month an award is given the department having the best record of cleanliness and orderliness. Our Welding Department has taken first place many times attesting to their good housekeeping. The condition of the working area undoubtedly is reflected in the quality of the job produced.

Servel enjoys the reputation of not only a well-manufactured product, but one of highest quality.

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Military Aeronautical Spot- and Seam-Welding Specifications

The development of specifications governing the application of the spot- and seam-welding processes to military aircraft is traced. These specifications aim to encourage the growth of spot welding from a limited usage in noncritical and nonstructural applications toward full structural application

by J. Maltz and N. E. Promisel

THE use of spot welding for primary aircraft structures is older than we sometimes think. On display alongside the Franklin Institute in Philadelphia one may see the "Pioneer," an amphibious biplane built in 1931 by the Edward G. Budd Mfg. Co. to demonstrate the practicability of its "shot-weld" process of fabricating stainless steel—a process later used in the manufacture of streamlined stainless steel railroad trains. Jenkins and Piper[1] have recently pointed out that the Northrop Gamma Type plane had wings spot welded with home-made equipment and was in successful production as early as 1933. The Chance Vought Aircraft Division of the United Aircraft Corp. made extensive use of primary structural spot welding in the OS2U-1 "Kingfisher," a pre-World War II observation seaplane built for the Navy. The fuselage skin was spot welded to the formers, the stabilizer and fin skins to stiffeners, and the engine cowl skin to reinforcing strips. Nor is specification control of spot welding new. The original of Army Air Corps Specification No. 20011 was issued on January 27, 1934. The Bureau of Aeronautics maintained control over the spot-welding process during the 1930's by a circular letter of instructions to Navy inspectors.

In spite of the above it was necessary to limit the use of spot welding, in primary structural components for a good many years longer. The basic reason for this, of course, was limited experience. Other reasons included the uncertain consistency of the spot-welded joint, lack of knowledge of fatigue properties, uncertainty as to the corrosion susceptibility of spot-welded sheet, and lack of knowledge of whether the greater rigidity of the spot weld prevented it from distributing an overload to its neighbors as readily as a rivet. Where spot welding was permitted, rigid test requirements had to be designed to give assurance of quality control. As experience and research data have been collected there has been a gradual improvement in dependability, in design know-how and in over-all quality level which has made possible the easing of restrictions on the use of the spot-welding process.

The period between the first structural usage of spot welding and the early part of World War II was one during which a great deal of preliminary spot-weld evaluation work was conducted. The effects of pressure, time of current dwell, electrode contour, spot spacing and sheet thickness were explored.[2, 3] Corrosion resistance was studied, radiographic and metallographic techniques were developed.[4] The current-strength characteristics were established.[5] The difficult and extremely important problem of surface preparation was attacked and reliable cleaning procedures were established.[6]

It was logical to codify such a background of information so that it could be put to work to satisfy the demands of World War II. The Aircraft Resistance Welding Committee of the AMERICAN WELDING SOCIETY accordingly, in August 1942, released its excellent "Tentative Standards and Recommended Practices and Procedures for Spot Welding of Aluminum Alloys" as an emergency standard. (A similar pamphlet of recommended practices for low-carbon steel was not issued by the Resistance Welding Committee until 1946, with a revision in 1950.) The recommended practices for aluminum have never progressed beyond tentative form because the complexities of aluminum spot welding—high conductivity, shrinkage, oxide film removal, etc.—have complicated the task of agreeing on an accepted standard practice. The Resistance Welding Committee has continued its efforts, and, as this is written, the prospect of early publication of a code of recommended practices is bright.[7]

PW-6

On Oct. 14, 1941 the Bureau of Aeronautics issued

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Paper was presented at a joint meeting of the AIEE-AWS-IEESD at the Third Electric Welding Conference held in Detroit, Mich., Apr. 16 to 18, 1952.

its first formal spot-welding process specification: PW-6, "The Spot Welding of Aluminum and Aluminum Alloys," superseding previous instructions. This document was based upon work done at the Naval Aircraft Factory and Wright Field, together with information submitted by several aircraft manufacturers. Examination of PW-6 and comparison with current specifications quickly reveals the progress made in the past decade. PW-6 restricted spot welding to nonstructural and secondary structural parts only, except by specific Bureau of Aeronautics approval which was very cautiously extended. Only 2S, 3S, Clad 17S, Clad 24S, 52S and 53S alloys were accepted for welding. Minimum shear strength values which might reasonably be expected were listed for information only. Average values and ranges were not listed. For qualification of equipment 25 single-spot shear specimens, 25 U-type tension specimens and 5 single-spot metallographic specimens were required. A variation in strength of ± 10% of the average strength values was permitted in 21 of 25 specimens and ± 20% in the other four. During production, 5 single-spot specimens were to be pulled at two-hour intervals for routine check. Welding current was required to be controllable in 5% steps.

Three series of developments during the war years expanded the horizons of aircraft spot welding and promised to free it from its early restrictions. First, the manufacturers of equipment and controls demonstrated new energy and remarkable ingenuity in developing high-quality control circuits. Secondly, in 1941, the NACA, the Air Forces and the Navy Bureau of Aeronautics assumed sponsorship of the monumental work of Hess and his co-workers at the Rensselaer Polytechnic Institute. Dr. Hess studied nearly every phase of spot-welding process control—cleaning procedure, weld spacing, sheet thickness, inspection, test and quality control methods and optimum wave forms, to name some. The cooperation of the Welding Research Committee of the Engineering Foundation facilitated wide distribution of the resulting reports and their publication in The Welding Journal. Third, the Battelle Memorial Institute was commissioned to study the resistance of spot-welded joints to fatigue

The data obtained by these workers greatly influenced the writers of spot-welding specifications during the wartime period. The work of Hess in particular demonstrated that the field of usefulness of spot welding was scarcely touched; but it showed beyond doubt that spot welding had to grow and not merely to expand. It was necessary to make use of tools which were already available or rapidly becoming available to control the spot-welding process. Pressure had to be precisely synchronized with welding current and applied as a controlled part of the welding cycle. Design limitations had to be dictated, not by what could sometimes be accomplished, but by what could be accomplished with mathematical regularity. With these controls spot welding could grow in scope; without them it must remain static.

PW-6a

In 1943 an attempt was made to combine the Air Forces and Bureau of Aeronautics specifications for spot welding, inasmuch as wartime developments necessitated a revision of each. Since it appeared that full coordination would take some time, and since the Bureau of Aeronautics was convinced that spot welding in general would be desirably promoted by a specification revision which would reflect the technological advances developed at R.P.I. a proposed "a" revision of PW-6 was offered to industry. In this revision spot-welding applications were divided into Class A, critical or structural, and Class B, noncritical and nonstructural. Subject to a careful quality control, structural spot welding was thus accepted. Some may have claimed the acceptance was ephemeral in view of the difficulties placed in the way of full application, but the change in wording from

> "...restricted...except where authority to weld primary structures has been granted by the Bureau of Aeronautics" (PW-6)

to

> "Approval...(of Class A spot welding)...will be based on available evidence..." (PW-6a)

was nevertheless of real significance. A positive philosophy of acceptance of spot welding in primary structures was established.

The outstanding wartime work on improvement of spot-welding equipment design was recognized by inclusion of provision for a much greater variety of machines than those listed in PW-6. 61S and Clad 14S were added to the list of alloys acceptable for welding, as was Clad 75S in thicknesses over 0.032 (selected as a heavy enough gage to minimize the possibility of structural failure by intergranular corrosion and to give reproducible results under the spot-welding electrode). The requirement was added for Class A spot welding that the members joined could not differ by more than a 1:3 thickness ratio without bureau approval, nor could more than two thicknesses be joined at one time without such approval. A number of additional certification and inspection tests based on the newer control equipment were proposed and, in some cases, strongly opposed by segments of the industry. There was some feeling that Qualification Tests, Routine Check Tests and Quarterly Check Tests presented too complex a control system. It was also stated that tests requiring laboratory instruments such as oscillographic or surface resistance measuring equipment should not be required though they should be permitted. One forceful commentator at this time wrote, "If research data are needed, they should be requested outside of a specification," thereby indicating his misunderstanding of the proposed

specification. Opposition to a proposal to radiograph 1% of all production spot welds was centered on the high cost of such a large sampling plan. Opposition to a proposal that government-tested specimens be required to certify each machine centered on the delays involved in such a procedure. Industry feeling was was by no means unanimous and representatives of the services several times found themselves acting as arbitrators between widely divergent viewpoints among spot-weld fabricators. Perhaps the most productive of a long series of conferences was held in Pittsburgh in November 1944. Representatives of the services, the equipment manufacturers, material vendors and nearly all the airframe builders considered the specification at length and brought forth an agreed-on draft.

The results of this vigorous discussion were evident when the PW-6a revision was released on Jan. 20, 1945. The test requirements were in general "toned down" from those originally proposed. No certification specimens, for example, were required to be submitted to a government laboratory. Radiography was required of 0.1% rather than 1% of all production welds. Force-current oscillograms were required, but only at monthly intervals. The V-type tension specimens were eliminated entirely.

Perhaps the most significant change in PW-6a involved the table of shear strengths. Table I of PW-6 had merely listed typical shear strength values for various material and gage combinations. The only mandatory requirement was one of consistency; in a group of 25 single-spot specimens a variation in strength of $\pm 10\%$ of the average value was permitted in 21 of the specimens and $\pm 20\%$ in the remaining four. This corresponded to a coefficient of variation of approximately 7.5%. Table I, of course, did not represent the highest strength welds obtainable. They were good values within the range obtainable in production. Considerably higher strengths could easily be obtained, but at the expense of quality and consistency. The philosophy was adopted that the optimum value for spot strengths is that which gives the greatest consistency, assures sufficient strength and produces the least deteriorating effect on the parent metal surrounding the spot.

The question of acceptable design shear strengths inevitably arose. Table I was misused in that the values therein were used by individual contractors for design purposes. Nevertheless there was inherent in the consistency requirement a very different interpretation. This was explored by Hess[8] and his coworkers, by Clark,[9] Robinson,[10] Butler[11] and by the Bureau of Aeronautics. Hess pointed out, for example, that to maintain the Navy strength of 180 lb. for *each* weld in 0.020-in. 24S sheet with a 7.5% coefficient of variation it would be statistically necessary to maintain an average strength for *all* welds of 225 lb. In addition it would be wise to introduce an additional safety factor which he called a "base strength factor" to take care of accidental machine variations. With a factor of 15% it would be necessary to maintain an average strength of 260 lb. to be certain of getting individual welds as strong as 180 lb. Inasmuch as the experience at R.P.I. indicated an average strength value as high as 285 lb. could be obtained in sound welds in the 0.020 gage for 24S alloy the Navy value would serve reasonably well when correctly used.

In PW-6a an effort was made to promulgate this sort of philosophy in a form which would be more easily digested by design engineers and inspectors. Table I of PW-6 was replaced by Table II of PW-6a, headed "Maximum Shear Strength Values for Design." Values were lowered somewhat because they were not to be typical values, but design figures. A contractor could use lower design values if he wished, but in any case the average shear strength of the 25 certification specimens for Class A welding was required to be at least 15% above design values. This was the safety factor proposed by Hess.

Perhaps not adequately answered by PW-6a was the question of how to interpret the routine check specimens used for production quality control. If a 25 specimen certification test is allowed a certain minimum average value it is evident from statistical theory that a smaller inspection sample should be allowed to give a lower average value to reflect the same quality standard. In this connection PW-6a, to provide flexibility of statistical methods, merely provided that "the values from the (routine check) shear strength tests shall be suitably plotted to show that statistical trends are within the acceptable limits for variations."

AN-W-30

Up to this point the authors have traced the development of the Navy Bureau of Aeronautics specification for aluminum alloy spot welding. The development of Air Forces philosophy has not been examined in detail for the obvious reason that the authors have been more closely associated with the Navy work. One major difference existed between the Air Forces and Bureau of Aeronautics specifications. The former covered the spot welding not only of aluminum alloys but also of magnesium alloys, steels, nickel-copper alloys and nickel-chrome-iron alloys. In 1946 a decision to place the spot welding of light alloys in one specification and heavy alloys in another paved the way for coordinated Army-Navy Aeronautical Specifications AN-W-30 and AN-W-32.

PW-6a had not permitted the spot welding of bare high-strength aluminum alloys because of the adverse effect on corrosion resistance, always a major consideration for sea-going material. When issued (on Jan. 17, 1947) AN-W-30 accepted the more liberal Air Forces policy of allowing one member of the spot-welded combination to be bare, on the basis that the cladding on the one member would offer some protection to the other. In the case of seaplanes and amphibious planes, however, specific authorization was required. Whether the authorization would be granted, of course,

depended on the degree of exposure of the joint in question, the thickness of the members involved and on structural considerations.

It has been mentioned that the shear strength tables of PW-6a represented figures for design. At the request of users of spot welding, these design figures were now moved to ANC-5 Bulletin, a publication issued jointly by the Navy, Air Forces, and Department of Commerce (Civil Aeronautics Administration) as a handbook of design criteria. Table II reverted, in AN-W-30, to a table of requirements which test specimens must meet. The two documents—the specification and the design bulletin—were tied together by making the design figures 80% of the minimum values required by the specification. A change in one would of necessity require a change in the other.

In addition to listing a *minimum* strength value, which every spot weld tested had to meet, AN-W-30 gave a figure for the *lowest average* permitted in a group of test specimens. A further refinement was added in Amendment 1, dated Feb. 19, 1948, when the demands of statistical theory were met by making the required minimum average a little higher for a sample size of 20 (the certification test sample) than for a sample size of 3 (the hourly check test sample).

Shear strength requirements for magnesium alloys had not been listed in Air Forces Specifications 20011. Preliminary data now became available and were included in AN-W-30. They were not wholly satisfactory, however, in that no distinction was made between the higher strength and lower strength alloys. With the cooperation of the Aircraft Industries Association, the Dow Chemical Co. and the Aluminum Company of America this deficiency was corrected and a workable breakdown was issued as part of Amendment 1.

Increasing familiarity with, and confidence in, Clad 75S allowed a relaxation of the prohibition on welding gages of 0.032 or below so that it applied only to material less than 0.020 in. thick.

Radiography of 0.1% of all production welds, which has been mentioned before as a requirement opposed by industry, was finally dropped in Amendment 1. Periodic sectioning was substituted. Radiography was also dropped as a requirement for certification of the welding schedule and was retained only as a procedure for qualification of the welding machine. As a matter of fact a clear-cut and much-needed distinction was drawn between the initial *qualification* of a machine and the *certification* of the welding process or schedule. The intent was to make the qualification (which established the full range of capabilities and reliability of operation of the machine) a rigorous procedure and the certification (which might apply to a single production setup) a less time-consuming affair.

Several other provisions carried over from both PW-6a and No. 20011 were eliminated by AN-W-30 or by Amendment 1. One was a dimensional tolerance of $\pm 1/8$ inch on the spot spacing shown in the drawing. Welding engineers had argued with considerable justification that this was a design matter and not a proper detail for inclusion in a specification. Another was the requirement for periodic force-current oscillograms. Although their use is still recommended practice they are no longer used as specification material.

Seam welding was included for the first time in AN-W-30, but only in a manner reminiscent of the state of the spot welding art ten years before. Seam welding was restricted to applications which are noncritical and nonstructural and is still so restricted today. The authors will have more to say about this matter later in the paper. No shear strength values were listed.

AN-W-32

PW-8, covering the resistance spot and seam welding of nonhardenable steels, never progressed beyond the draft form before being absorbed in Army-Navy Aeronautical Specification AN-W-32, "Welding; Low-Carbon Steels, Austenitic Steels, and Nickel Alloys, Spot and Seam." In general form, this specification followed AN-W-30 very closely and, inasmuch as the spot welding of these materials has never represented more than a small part of aircraft usage of the process, it will not be examined here in as great detail as that specification.

Shear strength values in AN-W-32 were based on those listed in AAF Specification No. 20011-D. Data received from a variety of sources indicated that the requirements could be lowered to some extent without adversely affecting weld consistency or quality, and that particularly in the low-strength materials, some difficulty had been encountered by certain manufacturers in maintaining the required standards. Accordingly, AN-W-32 was prepared with somewhat lower values.

To consider this matter as well as a number of other controversial points—the strength consistency to be required in certification tests, the number of specimens desirable for machine qualification, the limit of what constituted excessive penetration, and the amount of change in machine control settings permitted without recertification were most important—the Working Committee of the Aeronautical Board (now the Aeronautical Standards Group) enlisted the cooperation of the aircraft manufacturers and the AMERICAN WELDING SOCIETY in the formation of a temporary advisory subcommittee. The subcommittee proceeded to circularize industry for comments on AN-W-32 and then, at a meeting held in Washington on Mar. 9 and 10, 1948, agreed on a mutually acceptable draft. AN-W-32 was formally promulgated a short time later.

NATIONAL MILITARY ESTABLISHMENT SPECIFICATIONS

The unification of the National Military Establishment inaugurated a policy of confining military specifications to a single series which would eventually

supersede specifications of a single service, bureau or local activity. Accordingly, on Aug. 7, 1950, AN-W-30 and AN-W-32 were renumbered MIL-W-6860 and MIL-W-6858, respectively. It was perhaps a tribute to the hard work that had gone into these specifications that the renumbering could be accomplished by the simple addition of a cover sheet without involving further extensive revisions. MIL-W-6858 and MIL-W-6860 are today the specifications governing the spot and seam welding of military aircraft.

FUTURE TRENDS

A recital of this type would not be complete without some discussion of the directions which future specification revisions may take. The authors would like to take this opportunity to suggest for consideration some new material relating to the spot- and seam-welding specifications. It is not offered in the form of firm proposals, but rather as personal observations designed to stimulate constructive contributions.

Strength Requirements

We have seen how the listing of strength values for spot welds has progressed from *typical strengths* to *design strengths* to *specification test requirements* intimately associated with allowable design strengths; and how the specification requirements now include a *minimum* requirement for each spot, a *lowest permissible average* for a sample under test (consideration being given to the effect of sample size) and a *consistency requirement*. While a great improvement, this is still not ideal. It requires that every spot tested meet the minimum. If so much as one spot of the 100-spot certification sample fails this requirement the entire set is rejected. Inasmuch as spot welds are used in multi-spot assemblies, this requirement may not always be necessary. It is suggested that it might prove practicable and be more logical to meet the strength requirements of a spot-welded assembly by listing just two functions: a minimum average and a statistical criterion of the spread.

The minimum acceptable average could readily be set much as it has been up to now, by examining good current practice and selecting a level on the distribution curve of the mean which could be expected to pass a predetermined percentage of all lots submitted — say 99.4%, corresponding to a permissible variation of 2.5 sigmas.

To establish the second criterion the 2.5 sigma point on the low side of the distribution curve for the individual weld population is first determined. Let us call this value U. Then 99.4% of all welds, judging by a survey of good current practice, may be expected to have shear strengths exceeding the value U. A plan is then set up with an AQL (Acceptable Quality Level) of approximately 5%, based on U as a cut-off point. In nonstatistical language, this requirement means that a lot having 5% if its members less than U would have a 95% chance of being accepted.

Dr. J. A. Greenwood of the Bureau of Aeronautics has worked out the mathematics of such a plan and suggests that the criterion for acceptance be defined by the equation:

$$\bar{x} - KR \geq U \qquad (1)$$

where $\bar{x}$ is the mean of the shear strength values of a sample of several welds, R is the range (difference between the largest and smallest values) and K is a calculated statistic which is substantially a constant to the degree if accuracy obtainable in spot-weld control.

The operation of this statistical plan will now be illustrated in connection with the strength of seam welds.

Seam Welding Allowables

The lifting of restrictions on seam welding will depend upon the compilation of experience upon which to base design strength, coupled with adequate control procedures to assure uniformity.

Some years ago the Bureau of Aeronautics requested the Naval Air Material Center to make a study of the seam welding of aluminum alloys. Strength characteristics and dependability primarily were to be investigated. Test procedures were also given consideration.

The technique used in this investigation was to request five different manufacturers of seam-welding equipment, or fabricators engaged in seam welding, to prepare welds in aluminum alloys of various compositions and thicknesses. These welds were subjected to mechanical tests as well as quality inspection. The test values were collected and, for each combination of alloy, thickness and temper, least squares were used to get adjusted values of the mean ($\bar{x}$) and standard deviation (σ). The statistical factors just discussed were then set up and the following table resulted:

Shear Strength, Lb. per In. of Seam

Thickness, in. →	*0.020*				*0.030*				*0.064*			
	Minimum average				*Minimum average*				*Minimum average*			
Alloy ↓	$N=3$	$N=20$	$N=100$	U	$N=3$	$N=20$	$N=100$	U	$N=3$	$N=20$	$N=100$	U
2S	330	342	346	316	615	631	636	596	952	968	974	933
3S	348	363	368	330	714	737	745	686	1114	1144	1153	1088
24S-T	635	702	726	554	1314	1395	1423	1217	2129	2226	2260	2013
52S	716	741	746	690	1226	1276	1294	1165	1812	1893	1922	1716
R301-T	678	701	709	650	1107	1163	1182	1041	1625	1717	1750	1544

Unfortunately, not enough welded sheets of the 618 and 758 alloys were returned to permit analysis of the data. In the case of the 28, 38 and 528 alloys the strength values obtained were much the same regardless of whether the base material was in the $^1/_2$H or the H condition.

The value of the statistic K in Equation 1 was calculated to be 0.30.

Let us now examine some hypothetical test samples for acceptability under the proposed criteria. Suppose a sample of three seam welds in 0.020 in. 28 sheet exhibited shear strength values of 300, 320 and 400 lb. per linear inch. Then

$$\bar{x} = {}^1/_3(300 + 320 + 400)$$
$$= 340 \text{ lb.}$$

which meets the requirement for minimum average.

$$R = 400 - 300 = 100$$
$$KR = 0.30 \times 100 = 30$$
$$\bar{x} - KR = 310$$

which is less than 316, and the sample is rejected.

If the values had been 300, 350 and 370 lb.,

$$\bar{x} = 340$$
$$\bar{x} - KR = 319$$

and the sample would be accepted.

If the values had been 315, 320 and 340 lb.,

$$\bar{x} = 325$$
$$\bar{x} - KR = 317$$

and the sample would be rejected for low average values, even though the spread is acceptable.

If the values were higher a greater spread would automatically be allowed; thus if the values were 310, 360 and 470 lb.,

$$\bar{x} = 380$$
$$\bar{x} - KR = 332$$

and the sample would be accepted.

To simplify routine calculations the range, R, was used in Equation 1 even though the standard deviation, σ, would be statistically more efficient. As an alternate to Equation 1 the use of

$$\bar{x} - K'\sigma \geqq U \qquad (2)$$

could well be allowed.

Spot Welding Titanium

The allures of light-weight, high-strength, excellent corrosion resistance and potentially unlimited availability have made titanium the subject of what is perhaps the most intensive metallurgical development effort in history. The resistance welding of titanium has received its share of attention. The Bureau of Aeronautics is sponsoring researches at the Naval Air Material Center and at North American Aviation on the spot welding of titanium.

In such characteristics as electrical and thermal conductivity titanium more nearly resembles the austenitic corrosion resisting steels than the aluminum alloys.

The spot welding of commercially pure titanium and the titanium alloys whose ultimate tensile strengths are less than 100,000 psi. (alloys which, in general, are strengthened by the effect of such interstitially distributed additions as nitrogen) appears to offer few problems. With the higher strength alloys—those of the TI-Al-Cr type, for example—a brittle phase is formed during the welding cycle. The investigation of postheats and other special treatments to eliminate this difficulty is contemplated.

It is evident that the data on the resistance welding of titanium are not yet sufficiently complete to be specification material. The aeronautical services would be pleased to have any additional data which may exist made available to them for evaluation.

The authors may appear to have slighted the aspect of this subject which is of most interest to many members of the American Institute of Electrical Engineers—the design and performance capabilities of resistance-welding equipment. The omission was intentional, though hardly meant as a slight. The Bureau of Aeronautics has accepted spot welding on a performance basis and has attempted to have its process specifications so written that any proved type of equipment is permitted. The development of accurate and dependable process-control equipment has been encouraged, but the mechanics of that development have been left to the equipment manufacturers' engineers, where they belong. Together with the airframe manufacturers who seek a more efficient way to build their aircraft and the aeronautical services who look for the maximum production compatible with top quality, they will extend the usage of resistance welding to a level far beyond that of the present day.

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Process Control for Resistance Welding Under Government Specifications

A realistic approach to conformance with military specifications of the resistance welding of ferrous and nonferrous alloys. It covers the organization and administration of the welding group and control of the process

by Frank G. Harkins

Abstract

Many metal fabricators are currently faced with the problem of assembling army, navy and airforce materiel by means of the resistance welding processes. Stringent process specifications have been issued by the government in order to insure high quality welding. This paper describes a realistic approach to conformance with MIL specifications 6858 and 6860 which deal with the resistance welding of ferrous materials, nickel and cobalt base alloys and light metals such as aluminum. This process control procedure lies within the framework of the MIL specifications. It pinpoints the authority and responsibility for resistance welding operations; it shows the organization of a technical welding group for administration and control of the process; it describes a welder operator qualification procedure which requires each operator to identity his work; it proves that in welding metals in dissimilar thickness combinations—especially if the weld, in service, is subjected to high-temperature or vibrational loading—that the tension-shear test is not a reliable testing facility and recommends the extensive substitution of the macro-etch test. Data which has been gathered from 15 machines involving a total of 3280 tension-shear tests and 570 macro-etch specimens on 10 gages of material is presented. Through this data a relationship between nugget diameter and tension-shear value has been established. A tentative statistical control procedure which—if properly applied and interpreted—will not permit the production of substandard welding, is described.

Introduction

THE process control which is described in the following pages has evolved over some twelve years of operation under such specifications as AF 20011, ANW30 (MIL 6860), ANW32 (MIL 6858) and others. It represents a rational or realistic approach to the maintenance of high-quality resistance welding. Many of its features are conditioned by the requirements and specifications of such organizations as the General Electric Co., the Westinghouse Electric Co., Lockheed Aircraft Co., Boeing Airplane Co., Allison Division of General Motors Corp., Douglas Aircraft Co., Convair and several others.

The process control which is presented is not the ideal. It is costly to apply and to administer. That it produces satisfactory results is demonstrated by:

1. Welds which are satisfactory in service are consistently produced.
2. Solar Aircraft Co. holds a preferred rating from the procurement offices.
3. Customer acceptance of the product.

Because most of the parts which are fabricated are precision aircraft components for the major aircraft engine builders and manufacturers, it is essential that resistance-welding standards be equal to the minimum standards of the procuring agency and the customer. It is only good business to exceed these requirements wherever possible. Since it is recognized that quality cannot be inspected into parts, the proper place to begin a quality control program for resistance welding is before the parts come into the welding department. Process controls for material preparation, jigging or fitting are not a part of the discussion. It is assumed that the minimum requirements of material preparation have been met. It is also assumed that the equipment has been demonstrated to be capable of performing the required operation and that the power supply is adequate for the production of consistent welding, i.e. voltage regulation will be within 10% and no serious transient currents exist in the supply line. The discussion consists of two separate phases. The first deals with the process control of resistance welding as it has evolved over the period of the past twelve years and is currently in operation. The second phase describes a tentative statistical method under which we hope to operate within the next few months. Early indications are that the statistical method will show definite advantages. That it will reduce the cost of administration is highly doubtful.

It can be stated, however, that the use of the statistical method will establish more closely defined

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limits of variation. From this standpoint it appears to be desirable.

Discussion

Early in the 1941–1945 war it became apparent that contractors could not be allowed discretion in the use of resistance welding for the production of materiel for the armed services. Prior to this time manufacturers had engineering authority over their product. Resistance-welding standards were either nonexistent or loosely applied. The federal specifications, at the time, for resistance welding were unrealistic in many respects. Serious production control factors were completely overlooked. A typical example of the confusion which existed at the beginning of the armament program occurred in one of the plants of a major airframe manufacturer. A stored energy type spot-welding machine had been qualified for 24ST Alclad aluminum. The production part required a different throat depth, arm spacing and the use of offset electrodes. At the time of the routine test specimen it was discovered that the tension-shear test did not come up to the minimum requirements. The machine was then adjusted to the same conditions as were used in the qualification procedure. This involved change of electrodes, arm spacing and throat depth. The test specimen then demonstrated the required value. At every subsequent routine test this same procedure was carried out.

Under conditions such as these it is understandable that a stringent process specification was developed. Solar Aircraft Co., as a subcontractor, fabricates parts under the specifications of at least fifteen prime air-force contractors. All of the specifications must fall under the MIL 6858 or 6860. The question naturally arises: "Why is it necessary for prime contractors to use their own specifications rather than those of the air-force, of the navy or other federal agency?" Or to localize the question, "Why must Solar Aircraft Co. have a resistance-welding specification other than the military specifications?"

It is much easier to answer the second question than it is to answer the first. As a subcontractor, Solar standards must meet the minimum requirements of the most stringent prime contractor. To insure acceptability under the specification we must exceed these requirements in order to allow a safety factor should some unpredictable factor be introduced. For example: The acceptable penetration lies between 20 to 80% of the thickness of the thinner sheet. It is standard procedure in our shop to hold nugget penetration between 30 to 70% as limits. This allows Inspection to purchase parts which do not meet shop standards, thus avoiding loss of expensive materials.

Probably the answer to the first question is that contractors feel that the MIL 6858 or 6860 is the minimum acceptable standard. As regards such companies as General Electric, Westinghouse, Lockheed and Boeing, I am fairly certain that this is the situation.

There appears to be little point in publishing the *Solar Standard Practice Bulletin on Resistance Welding* or the *Resistance Weld Instructions* of our Quality Control Division. There are, however, several points in our process control which are worthy of mention.

Of primary interest is the fact that we have been obliged to pinpoint the responsibility for resistance-weld quality. Our *Resistance Weld Instructions* states: "The production foreman accepts full responsibility for the quality of the work which is processed in the department...." The necessity for this decision may not be clear to some. Since one of the greatest aids to consistent high-quality welding lies in proper material preparation, joint preparation and proper fit of the parts which are under control of the production foreman, it is only reasonable to place the responsibility for weld quality on this individual.

The organization of the Welding Department also may be of interest. This is as shown in Fig. 1. It must be pointed out that this organization is responsible for only the technical aspects of welding. It does not exercise direct supervision of production welders. Production welders are under the supervision of the production foreman. The welding technicians are assigned to the Manufacturing Engineering Division and are responsible to the welding engineers. The welding technicians have authority to establish all welding procedures which are released to production in the form of resistance-welding data cards. Along with the Inspection Department, the technicians are responsible for ascertaining that these procedures are carried out. They are also responsible for the development of the best standards for resistance welding and all matters that have to do with increasingly better welding practice from the standpoint of quality, quantity and cost.

The set-up man is assigned to the Production Division and is responsible to the department supervisor in matters regarding department operation and organization. He is responsible to the welding techni-

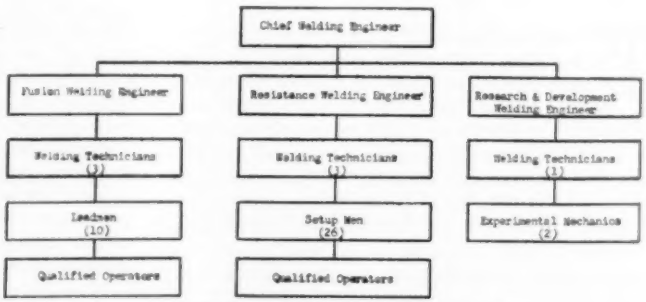


Fig. 1 Organization of Welding Department

Machine # _____ Day # _____ Date _____

Dwg. No. _____ Name of Part _____

Operation to be Performed _____

Type of Weld _____ Material _____ Surface Prep. _____

Electrode Top No. _____ Change _____

Electrode Bottom No. _____ Change _____

Mat'l Type & Gauge _____ Min. Shear Strength _____ Nugget Dia. _____

Transformer Tap _____ Distance between Arms _____ Throat Depth _____

Welding Pressure _____ Time _____ Cycles Heat _____ %

Sequence Panel: Squeeze _____ Hold _____ Pulsation _____ on; _____ off

Speed _____ Spots per minute or _____ Inches per minute

Number welds per inch _____

Welding Technician _____ Welding Engineer _____

Fig. 2 Sample welding data card

cians in all matters regarding actual welding operations and has the authority to stop a welding operation if for any reason he considers it to be an unsatisfactory welding condition. The typical welding data card is shown in Fig. 2. A data card is established for each welding operation and contains all of the necessary information to adjust the welding machine and to maintain a high quality weld for the duration of that particular welding operation. Data cards on routine fabrications may be established by the set-up men; but, all cards must be approved by a welding engineer or a welding technician within eight hours of the time of their issuance.

Another interesting feature of the Solar process control system lies in the fact that all welding operators must be qualified. In the operator qualification procedure, it is again necessary to pinpoint responsibility. Operators who have not qualified under the prescribed test are prohibited from performing spot and seam welding except as helpers under the direction of a qualified operator. It is the joint responsibility of the set-up man and the Inspection Department to administer the test and to carry out the above requirements. The qualification test consists of a demonstration of the candidate's ability to operate the equipment and his familiarity with the various adjustments. The candidate must install and adjust electrodes, adjust the air pressure, the stroke and electrode alignment. He must adjust the sequence panel to the proper squeeze, weld, "hold" and off times. He must demonstrate the pulsation welding technique and also must demonstrate his ability to adjust upper and lower horns for "bar" or "offset" setups. Each candidate must weld 10 single-spot specimens of each of the following: 0.018 to 0.018; 0.125 to 0.125; and 0.018 to 0.125. One specimen of each combination is used for a "peel" test. The specimen must tear out a nugget. One specimen of each group must be used for a macroetch examination. Penetration must be 30 to 80% of the thickness of the thinnest piece over 80% of the diameter at the faying surface. The remaining eight specimens from each combination are tension-shear tested in an approved tensile testing machine. Minimum tension-shear values are as follows: 0.018 to 0.018, 420 lb.; 0.125 to 0.125, 5700 lb.; 0.018 to 0.125, 480 lb. Each candidate must perform his own testing (peel, macro-etch, and tension-shear) prior to submitting final samples to the Inspection Department.

The seam welding qualification procedure is similar. Each candidate welds one 10-in. specimen of overlapping seam welds in the following gage combinations: 0.018 to 0.018; 0.078 to 0.078; 0.018 to 0.078. Each candidate also welds one 10-in. specimen of 1-in. center to center spots in the 0.018 to 0.078 gage combination starting $\frac{1}{2}$ in. from the end of the specimen. Each of the weld specimens as required above are sheared into ten 1-in. samples. The specimens of overlapping spots are tested as follows: eight of each set of samples are sectioned and etched. The penetration must be 30 to 80% of the thinnest piece. The remaining two specimens of each set are "peel" tested. These must tear out in the parent material and follow closely the outer periphery of the nugget. One specimen is used for a macro-etch test. Penetration must be 30 to 80% of the thickness of the thinnest piece over a linear dimension of 80% of the nugget diameter. The remaining eight specimens are tension-shear tested in an approved tensile testing machine. These must demonstrate a minimum value of 480 lb.

Each qualified resistance-welding operator at the time he successfully passes the qualification test is issued a numbered rubber stamp to identify his work. This is one of the greatest aids to the successful application of a quality control procedure that we have found. Each part which is fabricated by the operator is stamped with the rubber stamp. It is a personal thought that when a man is required to sign his name to every piece of work which he produces, he tends to take pride in the work thus resulting in the production of a superior quality product.

Also, after the successful completion of the qualification test, each operator is given a badge which is worn at all times on the premises. This badge states, "Certified Spot Welding Operator." This has been found to be excellent psychology in that the mere issuance of the badge has added to the prestige of the individual among his co-workers.

It is realized that very few resistance-welder users make any attempt to certify or qualify their operators. Since we take pride in the quality of our products we will do anything to maintain and improve quality. Placing resistance-welder operators in the same general classification as the fusion welders is just another practice which tends to make the job more important. The cost of installing and maintaining the operator qualification procedure is so low that it is certainly worth, in terms of quality production, the time, money and effort which is expended.

By now it has become apparent that our process control, as currently operated, has four separate check points to insure the production of parts to a minimum quality standard. These are:

1. The trained weld technician who operates under the direct technical supervision of the welding engineers and who cannot be influenced or put under pressure by the scheduling or production department.

2. The trained set-up man who is under the direct supervision, in technical matters, of the weld technician; in matters relating to quality, he also operates in a sphere isolated from the pressure groups.

3. The trained welding inspector who reports neither to the technical group or to the production group but to a separate division; namely, the Quality Control Division in the company. This man, being disassociated from the technical and production group, is completely objective in his approach to the production part.

4. The qualified operator who, in technical matters, is responsible only to the weld set-up man and who has shown his ability and understanding of the welding operation by successful completion of a practical testing procedure.

By operating under such a system, it is evident that four individuals must err in order to produce parts of substandard quality. It probably has become evident that such a process control procedure is expensive to install and to administer. This is readily admitted; but, when it is realized that failure in service of one of our spot-welded assemblies may result in the loss of an airplane costing several million dollars, no process control is satisfactory if it allows any conditions which might contribute to poor workmanship.

Probably our most significant deviation from accepted process controls lies in the extensive substitution of the macro-etch test for the tension-shear test. It can be shown—especially in fabrications involving "thin" to "thick" members—that the tension-shear test is a negative testing facility. By this is meant that if the tension-shear test shows a weld of poor quality, undoubtedly the weld is substandard. If, however, the tension-shear test shows a weld to be of adequate strength it is not an infallible indication that a sound weld has been produced. Since approximately 80% of our weld applications fall into the dissimilar thickness category, our only choice is to use the macro-etched specimen as our routine test piece. If the macro-etch test reveals a nugget of sound structure, of adequate size and penetration—as called out on the welding data card—the tension-shear value will always exceed that of the minimum specification:

Objections to the routine use of macro-etch have been noted by several large aircraft manufacturers on the ground that:

1. It is expensive to control and administer.

2. Measurement of nugget diameter is not a criterion of tension-shear strength.

The first of these objections cannot be substantiated in fact. Over a period of four years' study the average time requirement for preparation and interpretation of a macro specimen is $2^1/_2$ to 3 minutes—depending on the size of the parts. Further, the cost of equipment to conduct macro-etch testing is significantly lower than the cost of a reliable tensile machine. For example: a small band saw; double end (coarse and fine) grinder; 2–5 amp. battery charger; etch pot and acid can be purchased for less than $300—even on today's inflated market. A tensile machine of the quality required by the MIL specifications would probably cost a minimum of $800. Our laboratory-type tensile machines, depending on size, have cost $3000 to $27,000.

It is apparent, therefore, that the premise that cost of a macro-etch specimen system is higher than that of a tension-shear system for process control cannot be substantiated.

As regards the second objection that the measured nugget diameter is not a criterion of the tensile strength it must be admitted that we cannot predict with precise accuracy the actual tension-shear value from careful measurement of nugget diameter. This is understandable when one realizes that variation in chemistry, temper, grain size, speed of testing, degree of offset loading, number of cold passes by the mill and several other factors have a profound effect on the tension-shear value and little effect on the nugget diameter. This is obvious by simply referring to the chart of test specimen requirements as shown in MIL 6858. For example: in 0.050-in. thick material, 150,000 psi. and over tensile strength, the average tension-shear value must be 2620 lb.; while for material of 90,000 psi. and over the minimum average value need be only 1855 lb. The nugget diameter may be the same in either case.

It is apparent, therefore, that the tension-shear test is somewhat an elastic yardstick and as such is questionable as a quality control medium.

It has been shown by Dr. Wendell Hess of Rennsalaer Polytechnic Institute, as far back as 1941 in a paper titled "Spot Welding Nickel, Monel and Inconel" and by the author in 1948 in a paper titled "Spot Welding Schedules for Nickel and Nickel Alloys" that in spot welding nickel, Monel and Inconel that if the ratio of nugget diameter to sheet thickness is 3, $3^1/_2$ and 4, respectively, that failure in a tension-shear test will be by tearing a nugget. "What then is the significance of the tension-shear value?"

In order to check the adequacy of the tension-shear test as a routine testing procedure, a group of test specimens involving the joining of 0.021 to 0.063, Type 321 stainless steel have been made. This combination of a 3-to-1 thickness ratio is permitted under MIL 6858. Twenty specimens were made on a routine machine adjustment, these are Group A. Twenty were made utilizing special electrodes in order to insure adequate penetration into the 0.021 material, these are Group B. The welding schedule was as shown in Fig. 3. Ten specimens from each group were subjected to the standard tension-shear test. Results were as shown in Fig. 4.

Routine Specimens Group A	Corrected Adjustment Group B
Machine..... Taylor-Winfield 100 kva. Single-phase #10396	Same
Force..... 400 lb.	Same
Time..... 6 cycles—60 cycle wave	Same
Current..... Approximately 5400 amp.*	5000 amp.*
Electrodes, top..... Class II, 3/8-in. Face, 1 1/2 in. Radius	Class XI (elkonite), 2 in. Radius
Electrodes, bottom.. Class II, 3/8-in. Face, 6 in. Radius	Class II 3/8-in. Face, 6 in. Radius

* Heat setting on the machine was identical; namely, low tap 62% heat.

Fig. 3 Welding schedule for test specimens

Group A	Group B
1. 660 #	1. 680 #
2. 680 #	2. 670 #
3. 700 #	3. 690 #
4. 680 #	4. 690 #
5. 680 #	5. 680 #
6. 680 #	6. 670 #
7. 680 #	7. 680 #
8. 690 #	8. 680 #
9. 700 #	9. 680 #
10. 700 #	10. 680 #
Average... 685	Average..... 680
Variation.. 6%	Variation.....3%

Fig. 4 Tabulation of tension-shear values of test specimens

It will be noted that there is no significant difference in the tension-shear value. Specimens in Group A averaged 685 lb. with 6% variation while those in Group B average 680 lb. with 3% variation.

$$\text{Variation} = \frac{\text{Highest Value} - \text{Lowest Value}}{\text{Average Value}} \times 100$$

expressed as a percentage

All are acceptable under the tension-shear requirements of MIL 6858. Five of the specimens were subjected to macro-etch examination. The minimum requirement for penetration according to MIL 6858 is 20% of the thickness of the thinnest outside piece over 80% of the nugget diameter at the interface. Under this requirement, the welds of Group A are not acceptable while those of Group B are acceptable. Typical macrographs of each group are shown in Fig. 5. While MIL 6858 requires the use of the macro-etch test this is not a routine or hourly procedure. Under the specification a macro specimen might be used for the initial test and tension-shear specimens taken for the routine samples. A slight flattening of the electrode which contacts the 0.021 material could cause loss of penetration resulting in the production of substandard parts. The routine test would show the process to be under control while Fig. 5 shows that a "no-weld" condition exists.

To further evaluate these welds the remaining five specimens of each group were loaded and subjected to heating. The equipment which was used for this test is shown in Fig. 6. It will be observed that this apparatus remotely resembles that used for "creep" or "stress-to-rupture" values.

The specimens were heated to 1600° F. as measured on the optical pyrometer. At 1600° the tensile strength of Type 321 stainless steel is 17,500 psi. A load of 33 lb. was placed on the specimen. Based on nugget diameter this corresponds to a load of approximately 8250 psi. All of the welds in Group A failed in the weld before 1600° was reached. A typical failure is shown in Fig. 7 (*A*). All of the welds in Group B successfully passed this test. In Fig. 7 (*B*) the photog-

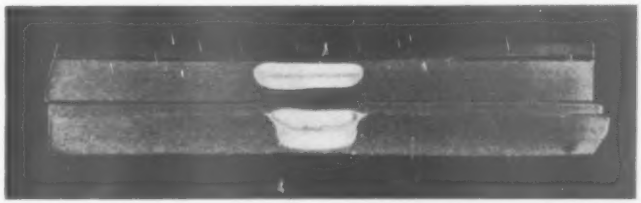


Fig. 5 Macro-etched specimen of 0.021–0.063 stainless steel

Fig. 6 Photograph of high-temperature test equipment

rapher tripped the shutter just as the specimen failed. While the picture is somewhat blurred and his exposure time was not adjusted for moving objects, the action may still be distinguished. The temperature was then increased to 1800° F. on the Group B specimens. Two of the specimens failed by tearing a nugget after approximately a 5-min. exposure. The remaining three specimens did not fail after a 10-min. exposure.

It is obvious, therefore, that for fabrications involving joining dissimilar thicknesses which are subjected to elevated temperature service, that the tension-shear test cannot be used to control weld quality. It also is obvious that the macro-etch test is a reliable testing medium.

It has been pointed out by numerous stress engineers that their interest does not lie in the nugget diameter as such but rather in the load carrying ability of the various spot welds. To answer this objection it was necessary to review the certification reports of a group of welders. We selected 15 different machines. These machines had been certified and qualified by different operators, inspectors and airforce procurement personnel. The results of this analysis are tabulated below. There were 3280 tensile tests and 570 etched specimens. The data on each gage is the summation of a minimum of 300 tension-shear specimens and 45 nugget diameter measurements. This data is tabulated in Fig. 8.

Figure 8 shows conclusively that if the nugget diameter is held to a predetermined level, the weld strength cannot fall below the "average of 20" tension-shear strength requirement of MIL 6858. According to the specification the "average of 20" value is approximately 18% above the minimum acceptable value. If the process control has been established to take advantage of the normal distribution (Gaussian) curve which allows variation from the average value of plus or minus 10% in 86% of the samples and plus or minus 20% in the remaining 14% of the samples, it is possible to accept substandard weld-

Fig. 7 (A) Photograph of high-temperature test results

Fig. 7 (B) Photograph of high-temperature test failure

Gage	Range Of Nugget Diameter	Average Nugget Diameter	Minimum T. S. Value	Maximum T. S. Value	Average T. S. Value	MIL 6858 Value
0.018	0.110–0.130	0.120	510	690	592	415
0.025	0.115–0.165	0.134	707	1005	802	655
0.032	0.144–0.165	0.155	1018	1440	1109	955
0.037	0.159–0.187	0.171	1224	1533	1366	1185
0.044	0.171–0.218	0.189	1631	2013	1776	1530
0.050	0.198–0.218	0.205	1969	2231	2130	1855
0.063	0.203–0.284	0.239	2599	3136	3028	2530
0.078	0.250–0.305	0.283	3716	4610	4035	3580
0.093	0.281–0.354	0.310	4680	5239	4904	4590
0.125	0.280–0.400	0.351	6290	7320	6921	6250

Fig. 8 Tabulated data of 3280 tensile tests and 570 etched specimens

ing even though the process is under control. For example: The tension-shear value for 20 specimens of 0.093-in. thick material as called out in MIL 6858 is 4590 lb Twenty per cent of this figure is 918 lb. which when deducted from the 4590 figure would allow acceptance of a weld which had a tension-shear value of 3672 lb. The minimum acceptable value under MIL 6858 is 3718 lb.

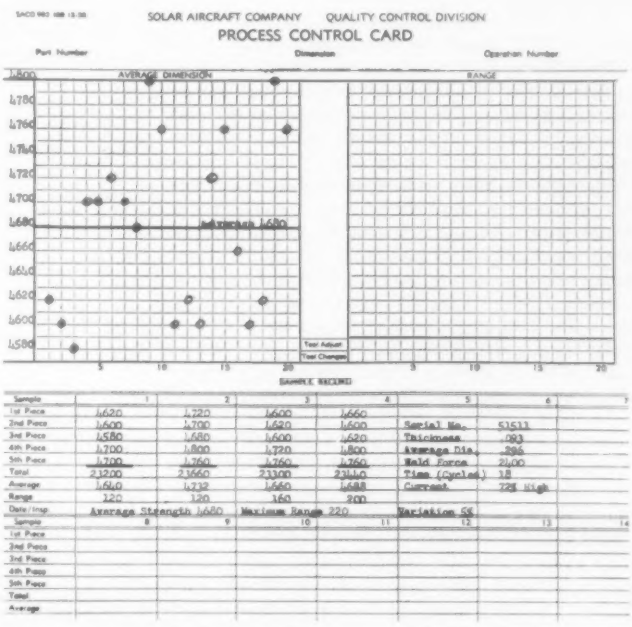
Several attempts to establish the statistical method of process control for spot weld have been made in recent years. As far back as 1944, major airframe manufacturers have experimented along these lines with varying degrees of success. To my knowledge, no airforce or navy contractor is currently using this process control method in resistance welding operations. Previous attempts have been largely unsuccessful for the same reasons that the "weld recorders" of a few years ago were not quite satisfactory. There are too many variables which have a profound effect on weld quality which cannot be accurately controlled under existing Aeronautical Material Specifications. Even the welding machine itself must stand careful scrutiny. Modern resistance-welding equipment is a far cry from the machines of 1944 and earlier. Machine manufacturers have recognized the problem and have attempted to improve the equipment so that today's machines are so complex that it requires practically an electrical engineer to open the door on the control panel. That progress in machine design has been made cannot be denied. Modern machines contain low inertia heads for fast follow-up forces; dual pressure systems along with trailing currents allow crack-free welding in crack-sensitive alloys. Three-phase machines give numerous benefits in weld quality, consistency and power demand. Slope control is advantageous in some applications.

Today's resistance-welding machine is approaching the status of a precision instrument. With this improvement in the quality of the apparatus it appears that it may be possible to establish some sort of a realistic statistical control procedure. This has been under investigation in our plant in San Diego for approximately one year.

The present trend in process control is toward the statistical method. This not only attempts to apply the scientific approach to the problem but also presents data which formerly was overlooked. It is not the desire of the author to attempt to masquerade as a statistician. It is also appreciated that statistics as a science has been much maligned by a group of well intentioned but misled individuals. Some years ago the story was told that there are three kinds of liars: the plain liar, the damned liar and the statistician. Another old chestnut is that statisticians have shown that if the number of men who fall asleep at technical meetings were laid end to end everybody would be more comfortable. Our interest in the statistical method lies only in its ability to control the production of parts so that increasingly better quality may be procured.

The successful application of any statistical method depends on standardization of all controllable factors. As previously noted the welding machines are now precision-type equipment. On a recent shipment of seven new machines we were able to use the same adjustments within the allowable limits for qualification and certification on all machines. While no attempt to measure the surface resistance of the material was made, the processing of all samples was identical. Electrodes of the same type and contour were employed.

A typical Process Control Card for 0.093 stainless steel is shown in Fig. 9. It will be noted that four groups of five specimens each have been tabulated. The average tension-shear value of 20 specimens is 4680 lb.; the average nugget diameter of five specimens is 0.296 in. The total range is 220 lb.; the range of the nugget diameter is 0.070 in. It has been demonstrated from the chart on Fig. 8 that if the nugget size is held to 0.281 minimum the tension-shear value can never fall below the 4590 average of 20 specimens as called out by MIL 6858. The minimum nugget diameter which would allow 86% of the specimens to fall within plus or minus 10% of the average value and


SOLAR AIRCRAFT COMPANY QUALITY CONTROL DIVISION

PROCESS CONTROL CARD

Part Number Dimension Operation Number

AVERAGE DIMENSION RANGE

4800 4780 4760 4740 4720 4700 4680 4660 4640 4620 4600 4580

Average 4680

Tool Adjust Tool Changed

5 10 15 20 5 10 15 20

SAMPLE RECORD

Sample	1	2	3	4	5	6	7
1st Piece	4620	4720	4600	4660			
2nd Piece	4600	4700	4620	4600	Serial No.	61611	
3rd Piece	4580	4680	4600	4620	Thickness	.093	
4th Piece	4700	4800	4720	4800	Average Dia.	.296	
5th Piece	4700	4760	4760	4760	Weld Force	2400	
Total	23200	23660	23300	23480	Time (Cycles)	18	
Average	4640	4732	4660	4688	Current	725 High	
Range	120	120	160	200			
Date / Insp.	Average Strength 4680		Maximum Range 220		Variation 5%		

Sample	8	9	10	11	12	13	14
1st Piece							
2nd Piece							
3rd Piece							
4th Piece							
5th Piece							
Total							
Average							

Fig. 9 Typical process control chart

14% of the specimens to fall within plus or minus 20% of the average value has not been determined and from a practical standpoint need not be determined since by holding within the required range it is not possible to produce a substandard weld. It has been calculated and empirically demonstrated by our statistical control group that in holding the nugget diameter to the required level that we actually have moved completely above the average value as shown on the normal distribution curve which is centered about the average of 20 specimens as called out in MIL 6858.

Specimens in groups of three are taken at:

1. Intervals not exceeding one hour.
2. Time of change of electrodes.
3. The start of each production run.
4. The end of each production run.
5. The start of each shift.

Should the nugget diameter (average of three) fall below the minimum called out on the data card the entire run of parts from the previous satisfactory test are rejected and are submitted to the Material Review Board for disposition.

It has not been shown mathematically that the standard group of three specimens will adequately control the process. Based on (*a*) reports of field failures, (*b*) acceptance of the product by customers and (*c*) preferred rating by airforce procurement personnel, the process control is satisfactory.

The instrument which is used for nugget diameter measurement is the "pocket comparator" by Bell and Howell. This allows fast accurate measurement to 0.002 in.

As previously indicated, the control limits are established for a sample of five for each combination to be welded. These limits consist of an allowable average nugget size and an allowable dispersion limit (range) from that average. The limits are placed on the weld data card which is attached to the machine for each operation.

The inspector, when making his periodic inspection, takes a sample of three macro-etched tests from the machine and averages the measured nugget sizes. He then determines the difference between the largest nugget and the smallest nugget to ascertain that the variation in nugget sizes is within the allowable range limit. He then compares the average and the range of the sample of three with the pre-established control limits on the data card. If the average and the range are within the controlled limits, the process is allowed to continue. If, however, either the average or the range exceeds these limits, the inspector stops the operation until the condition causing the lack of control is corrected. At this point all of the parts which were fabricated in the interim between the last satisfactory sample and the defective sample are rejected.

This form of process control is based on "Shewhart's Control Chart for Variables." Detailed information regarding its application and development may be found in any textbook on the subject.

Summary

The process control for resistance welding as applied at Solar Aircraft Co. lies within the framework of MIL 6858 and 6860. It is also in conformance with the specifications of some fifteen major airframe and aircraft engine manufacturers.

In order to standardize procedures it is necessary for Solar to meet the requirements of the most stringent specifications of our customers. As a matter of operating procedure it is necessary to exceed these specifications in order to eliminate extraneous factors which may have a deleterious effect on the weld.

Significant differences exist between Solar standard procedures and those of fabricators in similar activities. These differences are conditioned by factors which are peculiar to the high-temperature field of industry.

The process control as outlined is applicable to any user of resistance-welding equipment. That it fulfills its intent is exemplified by years of production of satisfactory parts.

The major differences between the Solar process control and that of other fabricators is as follows:

1. A well-organized welding department devoted entirely to the control and technical aspects of welding.
2. Direct lines of authority and responsibility from the executive to the shop level.
3. Qualified, trained welder operators who sign their name to every part which they fabricate.
4. More rigid standards than those required by other fabricators.
5. Extensive substitution of the macro-etch test for the tension-shear test.
6. Accurate records of routine tests.
7. A process control organization which is disassociated from production or scheduling pressure.
8. A welding data card which is established for each welding operation in the plant. If an operation is performed on more than one machine, a card is established for each machine.

The able assistance of D. O. Samuelson, Resistance Welding Engineer, Solar Aircraft Co., is acknowledged.

Sincere thanks is given to the Solar Aircraft Co. Research Division and Quality Control Division for their aid in the preparation of the illustrations and the inspection records.

Inert-Gas-Shielded Arc Consumable Electrode Welding

A description of the sigma welding process including equipment, gases, electrodes, current and some interesting applications

by H. E. Rockefeller

INERT-gas-shielded arc consumable electrode welding is quite a mouthful to say when referring to a process. It is easier to say sigma welding. Each of the letters in sigma represents one of the words used to describe this process; "s" for shielded, "i" for inert, "g" for gas, "m" for metal or metallic and "a" for arc. This easy-to-say word, sigma, is a nontrademarked word and is used in the same sense as oxyacetylene welding, gas cutting and brown dog.

INTRODUCTION

As in the case of its predecessor, Heliarc welding, sigma welding depends upon the use of an essentially inert gas to protect the molten metal in place of the combustible products and/or flux used in other metallic arc-welding processes. The characteristics involved in the transfer of metal across the arc in an inert atmosphere vary considerably from those in the atmosphere produced with coated electrodes. The necessity of providing a continuously flowing stream of inert gas, and of using current densities considerably higher than commonly employed in other welding processes, has largely dictated the types of mechanisms thus far employed to apply sigma welding. The high current densities limit the size of the electrode which has been used in automatic welding. This electrode size has been further limited in manual welding by the practical necessity of feeding the wire a considerable distance mechanically and continuously into the inert-gas-shielded space surrounding the arc and molten puddle. Fundamentally, the automatic application of sigma welding employs generally the same mechanisms used in other welding processes. However, for manual sigma welding, stick-type electrodes have not been found to be practicable, and the sigma welding mechanism employed involves a flexible wire-carrying cable between the torch or electrode holder and a motorized wire feeding device. Therefore, in basic principle, the mechanism is similar to that previously used for manual submerged melt welding.

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Presented to the Chicago Section of the AMERICAN WELDING SOCIETY, Feb. 15, 1952.

STUDY OF WELDING ARCS

The study of the sigma and Heliarc arcs has been the subject of a large amount of fundamental research. Arcs in inert atmospheres appear to be more readily investigated than metal arcs in other atmospheres because of the relative stability of sigma arcs, the higher and more uniform rate of droplet transfer and the consistency of the gas envelope.

One of the studies which has aided materially in our understanding of the mode of metal transfer existing under different welding conditions involves the use of ultra slow-motion pictures taken with high-speed cameras. In these studies, means were developed for taking motion pictures of the sigma arc at a camera speed as high as approximately 14,000 frames per second. This is equivalent to a passage of 100 ft. of film through the camera in about 0.5 of 1 sec. Looking at it another way, the viewing time of about 15 min. is equivalent to only about 1 sec. of actual picture-taking time. These slow-motion studies have really helped us understand what happens to metal transfer in the arc.

SIGMA WELDING EQUIPMENT

Let us briefly review the equipment used for sigma welding. Figure 1 illustrates a complete rod feeding and welding assembly. As can be seen, the unit consists of a rod reel and wire drive assembly, an inert-gas and electric control panel, a flexible cable through which the wire is driven and a torch in which is incorporated a trigger for initiating the flow of gas and welding current. Wire feed is initiated automatically when the arc is struck. The separate cable shown incorporates a small potentiometer which may be remotely set to establish the desired electrode feed speed.

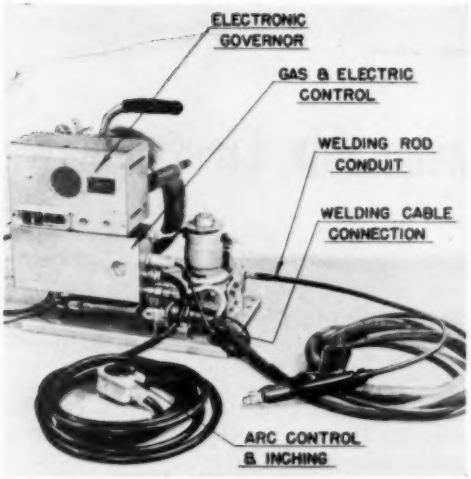

Fig. 1 Equipment used for sigma hand welding

In machine welding operations where lightness and flexibility do not tend to dictate small rod sizes, greater economy is obtained through the use of larger electrode diameters. In order to insure constant conditions at the arc, it is desirable to incorporate in this mechanism a voltage control which does not depend upon the self-regulation employed on the manual unit. The machine shown in Fig. 2 has an electronic voltage control incorporated in the equipment to maintain the arc length constant over a considerable spread in the other variables involved.

CHARACTERISTICS OF SIGMA WELDING

Before getting into a discussion of the application of sigma welding, let us first consider some of the characteristics which appear to be common to all metals thus far investigated. In its simplest form, sigma welding depends upon the principle of balancing wire feed speed against the rate at which the metal electrode is melted and transferred to the base metal. This rate of melting is commonly called the burn-off rate. When a proper balance is established, the electrode may be fed into the arc at a constant rate, thus maintaining a constant arc length. In addition to maintaining this balance, current, wire size, shielding gas, type of current and welding voltage must all be such as to produce the required weld shape and quality at the least cost.

It has been established that the burn-off rate is proportional to the current, and that for each size and composition of wire there is a minimum current below which the arc stability cannot be maintained. Likewise, there is a maximum current above which it is usually more economical to shift to a larger size wire.

Figure 3 illustrates the usable current range in welding aluminum for three different electrode sizes, and the corresponding rod feed speeds necessary to maintain a balanced arc in an argon atmosphere using reverse polarity. Note that the larger the wire size, the higher the minimum and maximum usable current, and the higher the deposit rate for any current common to the three.

In Fig. 4, data are given for carbon steel similar to the data shown in Fig. 3 for aluminum. Here argon-sigma grade is used with reverse polarity.

ARGON-SIGMA GRADE

Argon-sigma grade consists of a small percentage of oxygen in highly purified argon. Droplet rate in this oxy-argon mixture has been as much as 50 times greater than in an atmosphere of pure argon, other conditions being the same.

This greatly increased droplet rate, with no change in current density, permits welding at higher speeds without undercutting. Coalescence of the weld metal is improved at increased welding speeds. The mixture also permits welding at lower current densities. This means that larger diameter, more economical rods may be used for a given welding current. Note that in Fig. 4 the minimum usable current in steel is considerably higher for corresponding rod sizes, and that the rate of metal deposition is also about double that for aluminum.

Use of this special argon is expanding the application of sigma welding on stainless and carbon steels. More welding operations can be performed, welding speeds

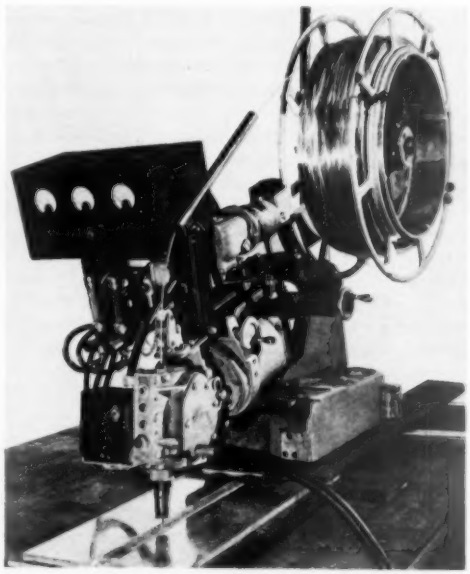

Fig. 2 Mechanized sigma-welding equipment incorporates a voltage control unit which maintains a constant arc length

Note: "Heliarc" is a registered trademark of Union Carbide and Carbon Corp.

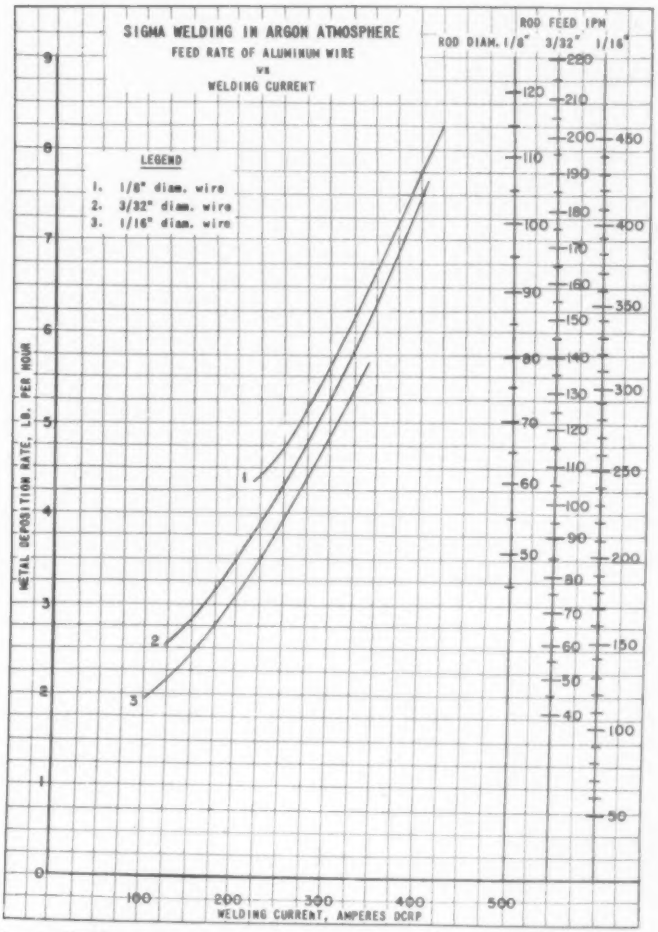

Fig. 3 Usable current range in welding aluminum for three different electrode sizes

can be doubled, gas consumption can be reduced, and less expensive rod can be used.

LARGE ELECTRODES MEAN ECONOMICAL WELDING

It is obvious from Figs. 3 and 4 that the larger the electrode, the more economical will be the deposited weld metal cost. Not only can higher currents and higher deposition rates be obtained, but the cost per pound of purchased wire decreases with increasing diameter. There are, however, limitations both as to the currently available equipment, and the thickness and type of joint being welded which dictate the maximum size of the wire that can be used.

In general, $^3/_{32}$-in. diameter wire cannot be used effectively on material less than $^1/_4$ in. thick; $^1/_8$-in. diameter wire cannot be used on material less than $^1/_2$ in. thick. The upper limit of wire size varies. For certain machine welding applications, larger diameter wire can be used than that used for manual welding, even where there are no limitations imposed by the feeding of the wire in manual welding. Furthermore, smaller than maximum size wires are often justified in spite of increased weld metal cost because of the greater control of the variables with the higher current densities normally used with the smaller diameter electrodes.

SHIELDING GASES FOR SIGMA WELDING

In the original investigations made of shielding gases for sigma welding, it was found, as expected, that the same general characteristics applied as in Heliarc welding. The arc voltage drop was higher in helium arcs than in argon arcs, and a larger quantity of shielding gas was required for protecting the arc and weld puddle. Furthermore, the arcs in helium were less stable and subject to discharging the molten metal outside the protecting envelope. As a result, spatter could not be controlled as readily as in argon arcs. It was also observed that the higher voltage in helium arcs spread the arc plasma over a wider area than in argon arcs. While for a given current, therefore, a larger nugget area was melted than for argon arcs, the weld penetration was usually greater with argon. Commercial application has generally supported these findings, and helium and helium-argon mixtures are finding few advocates.

During the research investigation of shielding gases for the welding of stainless and carbon steels, it was determined that argon required considerably higher current for suitable metal transfer than that required for welding aluminum. These currents were so high that very small diameter wires were required to maintain the current level within practical limits. Furthermore, lack of coalescence of the puddle and undercutting were encountered above certain current levels. It was discovered that the addition of small quantities of oxygen into the argon materially altered the arc characteristics at currents between 200 and 300 amp. without noticeably affecting the chemical composition of the deposited metal. The drop rate at a current of about 200 amp. was 30 to 50 times higher in the argon-

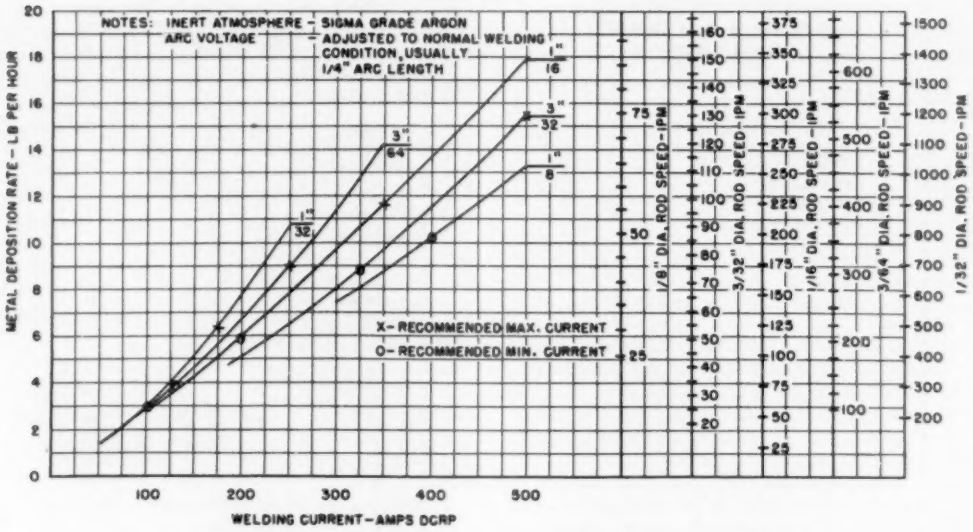
NOTES: INERT ATMOSPHERE – SIGMA GRADE ARGON
ARC VOLTAGE – ADJUSTED TO NORMAL WELDING CONDITION, USUALLY 1/4" ARC LENGTH
1/32"
3/64"
1/16"
3/32"
1/8"
X – RECOMMENDED MAX. CURRENT
O – RECOMMENDED MIN. CURRENT
METAL DEPOSITION RATE – LB PER HOUR
WELDING CURRENT – AMPS DCRP
1/8" DIA. ROD SPEED – IPM
3/32" DIA. ROD SPEED – IPM
1/16" DIA. ROD SPEED – IPM
3/64" DIA. ROD SPEED – IPM
1/32" DIA. ROD SPEED – IPM

Fig. 4 Usable current range in welding steel for three different electrode sizes

oxygen mixture than with straight argon. This resulted in the ability to use much lower currents for a given electrode size, or to use considerably larger electrodes for a given current. Welding speeds, it was found, could be at least doubled before undercutting or lack of coalescence were encountered. Welding conditions for carbon steel, already shown in Fig. 4 established that with argon-sigma grade, wire sizes for a given thickness of material comparable to aluminum could be used. The commercial possibility of using sigma argon on other than carbon and stainless steels has not been fully determined but laboratory investigations have indicated improved results with this mixture in the multipass position welding of aluminum.

WELDING CURRENTS

As originally developed and introduced, sigma welding employed reverse polarity exclusively. With reverse polarity it was determined that the drop rate for a given current and shielding gas was considerably greater than for straight polarity. The velocity of the molten particles was higher, and the base metal penetration for a given current density was considerably greater. Furthermore, in welding aluminum it had previously been established in Heliarc welding that straight polarity did not provide the required weld puddle cleaning action.

With the discovery of the advantageous arc characteristics of the argon-oxygen mixtures, interest in the commercial possibilities of straight polarity welding has increased. As in the case of reverse polarity, the arc of sigma-argon with straight polarity has permitted the use of sufficiently lower current densities to make straight polarity usable on steel and stainless steel. While the burn-off rate for a given straight polarity current is about 25 to 50% higher than for reverse polarity, and the penetration is less, these characteristics become advantageous in build-up operations. Further, and particularly for fillet welding, sufficient penetration can be obtained to make use of straight polarity commercially practicable. In addition, straight polarity has the potential advantage of minimizing dilution and reducing the magnetic effects associated with arc blow. Sufficient experience has not been established to forecast the field for straight polarity welding, but it is apparent that it will find increasing application as further experience is gained.

The importance of arc voltage as a variable in sigma welding seems to be predicated primarily on the effect of voltage variations on arc length. It is important that when the proper arc length is established, it should be held within small limits of arc length variation. Therefore, it is essential that the equipment provide means for maintaining relatively uniform voltage. Since the burn-off rate for a given current increased with decreasing arc voltage in reverse polarity welding, an increased burn-off rate results even though the power of the arc is reduced. This condition is reversed when the arc length is reduced to a point where the arc is shortened intermittently. Above a certain arc voltage, stability of the arc is lessened, and the tendency toward spatter is increased. However, voltage settings of between 24 and 30 v. will give satisfactory metal transfer across the arc.

SIGMA WELDING APPLICATIONS

Sigma welding was first introduced in the welding

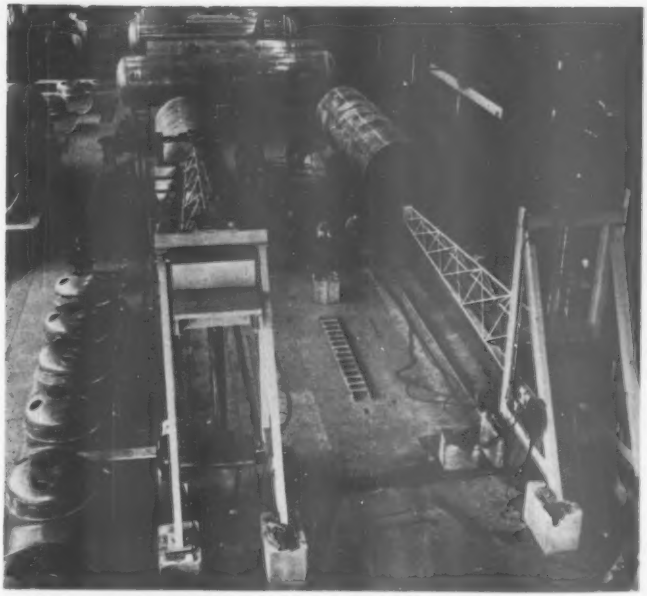

Fig. 5 Aluminum tank cars for transporting acids are fabricated by sigma welding

of aluminum and its application has been more extensive on this metal than on any other. It has, or is, rapidly replacing Heliarc welding on butt welds for materials heavier than $^1/_8$ in. and for some machine applications on lighter gage materials. Likewise, it is replacing coated electrode welding for fillet welding on structural joints, and additionally, has provided a means for joining aluminum on fabrications hitherto considered impractical for welding. The sigma process has proved well-suited to the welding of commercially pure aluminum, and several of its alloys.

Where applicable, sigma welding of aluminum is considerably cheaper than Heliarc welding and other welding processes. Compared to Heliarc, however, it has been more difficult to obtain comparable freedom from porosity. A large amount of research and development effort have been expended on the control and elimination of porosity in aluminum welding. For downhand mechanical welding, procedures and equipment were readily developed which consistently produced welds in commercial applications with no more, if as much, porosity than normally encountered in steel welding with submerged melt or coated electrode welding. Code X-ray standards developed for steel welds were easily met. For manual downhand welding, results equivalent to machine welding are being obtained commercially but, it must be admitted, without the same consistency, particularly, for multilayer welds. It has been well established, however, that where the wire is fed uniformly, and maintained within the protective inert envelope, and where relatively uniform arc length is maintained, results comparable to machine welds can be assured. Recent improvements in equipment and wire are simplifying the requirements for X-ray quality welds in manual downhand welding.

For multipass vertical and overhead welds in aluminum, porosity has been more difficult to control than for downhand welding. Mixtures of argon and helium have been claimed to offer some improvement over straight argon but laboratory investigations have recently indicated that sigma argon can be employed more effectively than any other inert gas or mixture for multilayer position welding of aluminum.

FABRICATING ALUMINUM TANK CARS

One of the earliest, and probably the most widely used, applications of sigma welding involves the fabrication of vessels. A good example is the fabrication of tank car tanks used in the transportation of acids.

Figure 5 shows a portion of a fabricating shop where aluminum tank car tanks are welded. Tanks have been constructed of 2S, 3S and 61ST aluminum in shell thicknesses from $^1/_2$ to $1^1/_8$ in. The shell diameter is approximately 7 ft. and the over-all length about 33 ft. To facilitate positioning of the equipment, the

Fig. 6 Making an inside weld in a tank car

automatic sigma welding head is mounted on a long fabricated cantilever beam. This beam can be raised and lowered for proper positioning. Two such welding assemblies are shown in the picture.

The plates are prepared and assembled with a 70-degree included angle vee about half through on the inside of the shell. The plates are formed so as to provide three longitudinal seams with no circumferential seams in the shell proper. The first pass weld is made from the inside as shown in Fig. 6. The weld is started on the end tabs shown, and the welding head is maintained in the stationary position on the boom as the shell is moved on a motorized carriage at the desired welding speed. The second operation is to back chip the longitudinal seams. On $^{3}/_{8}$-in. plate this is generally done to a depth of $^{1}/_{4}$ to $^{3}/_{8}$ in. The same machine then completes the weld on the outside of the tank in one pass making a total of two passes for $^{3}/_{8}$-in. plate.

After completing the longitudinal seams the heads are fitted to the shell. The thickness of the head is generally somewhat greater than the shell, and the flange of the head is reduced in thickness at the joint so that the abutting edges are the same thickness. The outside seam between the head and shell is first welded as shown in Fig. 7. The same equipment used for welding the longitudinal seams does this work. Then the head seams are, in turn, back chipped and welded from the inside. The final head closure is made with manual equipment.

Next the dome assembly is welded to the shell. The assembly consists of three parts, namely, a forged saddle, a spun head and a short cylindrical section fabricated from plate. These three parts are joined together by two circumferential welds. Then the assembly is fillet welded to the shell, part by machine welding and part with manual equipment. Figure 8 shows the machine fillet welding of the assembly to the shell.

Attached to the bottom and extending approximately one-third the length of the tank are two anchor bars machined from 1-in. thick extruded T sections. These are attached by means of a continuous fillet weld on both sides, and extending the length, of the anchor bars. The fillet also extends around the ends of the anchor bar. Manual sigma welding is used to attach the anchor bars to the shell, Fig. 9.

Upon completion of welding of all of the seams in the tank they are thoroughly X-rayed and any defective areas are chipped out and rewelded. The requirements for X-ray are the same as those that apply to steel welds as called for in the ASME Boiler Code. Repairs to welds as a result of X-ray examination are no greater than for steel tank construction. In the construction of aluminum tank car tanks several hundred thousand pounds of electrodes have been consumed. This gives you an idea of the extent of production of sigma welding on this class of equipment.

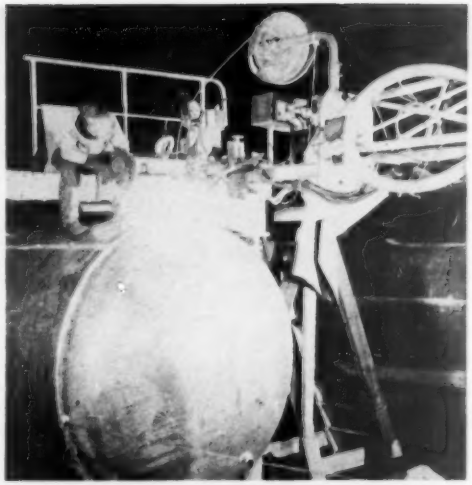

Fig. 7 Here the head and shell of a tank car are joined

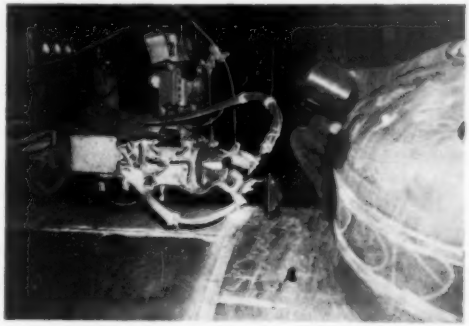

Fig. 8 A fillet weld joins the dome assembly to the shell

Fig. 9 Anchor bars are hand welded to the shell

Fig. 10 Lightweight deck bulks fabricated by sigma welding

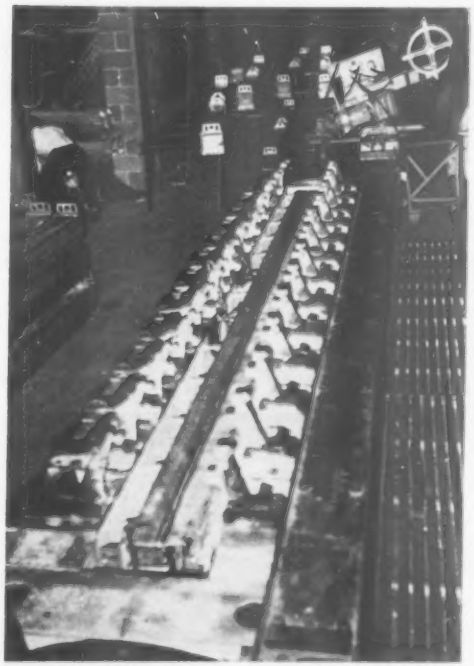

Fig. 11 An efficient fixture is used to line up and hold the parts during welding

Fig. 12 Here the fixture is being loaded with two halves of the deck bulks

Fig. 13 The welding operation

DECK BULK SECTIONS FOR PONTOON BRIDGES

Another interesting and high production application of sigma welding to aluminum is being made in the fabrication of lightweight deck bulks, Fig. 10. These sections are being used by our engineers in Korea in the building of pontoon bridges. The bulks form the roadway and are placed side by side lengthwise over the pontoons in place of the 12 x 12 timbers formerly used. The sections are made up from two channels which are welded face to face to form a section $8^{3}/_{4}$ in. x 9 in. x 14 ft. long.

In Fig. 11, we see the jig used for welding the deck bulks. The fixture has air-operated hold-down clamps which are pneumatically operated. Each clamp has two bearing surfaces top and side with contacts 6 in. apart.

The expandable section of the fixture is being loaded with two halves of the deck bulk in Fig. 12. An internal fixture containing copper back-up bars also contains a fire hose which, when pneumatically inflated, holds the back-up bars against the two joints. The internal jig is under air pressure as shown here and thus holds the two channels in alignment during loading.

Figure 13 shows the actual welding operation. The material is 14ST alloy and the thickness at the joint is $^{3}/_{16}$ in. The joint is being welded at a speed of approximately 60 ipm. with aluminum wire. After the first weld is made, the fixture is rotated 180 degrees and the other seam is then welded.

End plates are sigma fillet welded manually into the deck bulks to make the complete assembly watertight. After welding is completed, the bulk is inflated to 3 lb. air pressure and completely immersed in a tank of water to test for tightness. Some stacked deck bulk sections are shown in Fig. 14 after testing. The bottom row of bulks is aligned as they would be in service. Note that the two welds are on the neutral axis. The tread which forms the top of the bulk section can also be seen in this view. Several thousand of these sections are being welded at three locations.

Fig. 14 Stacked deck bulks after testing

ALUMINUM TRUSSES FOR PORTABLE HANGARS

A typical structural application of manual sigma welding of aluminum is shown in Fig. 15. This involves the fabrication of aluminum trusses from 61ST aluminum to be used for jet plant portable hangars.

Another view of the welding operation is shown in Fig. 16. Note the manner in which the sigma welding equipment is hung from a beam. This method of suspending the drive unit and rod reel permits the operator to make all welds on the truss without moving the equipment.

In Fig. 17 a number of completed trusses are stacked and ready for shipment. It will be noted they are constructed from angles and plate, and completely fabricated by fillet welding the cross members to the main members of the truss.

Fig. 15 Aluminum trusses to be used for portable jet plane hangars are made by sigma hand welding

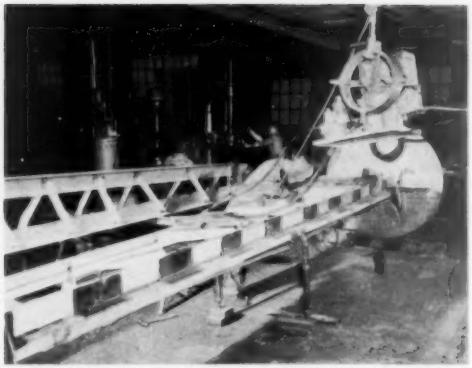

Fig. 16 By hanging the welding equipment on a beam, the operator can make all the required welds on the truss without moving the equipment

SIGMA WELDING COPPER BUSBARS

The sigma process seems to be exceptionally well adapted to the welding of copper and copper alloys. The high heat conductivity of copper, however, requires some preheat on material above $^{3}/_{8}$ in. in thickness. For the copper alloys where the heat conductivity is not as great, no preheating is required. An interesting application has recently been developed

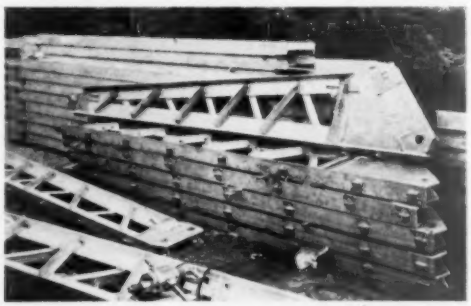

Fig. 17 Completed trusses ready for shipment

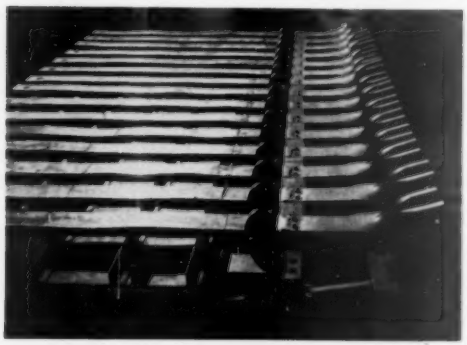

Fig. 18 Sigma-welded copper busbars ready to be removed from the welding jig

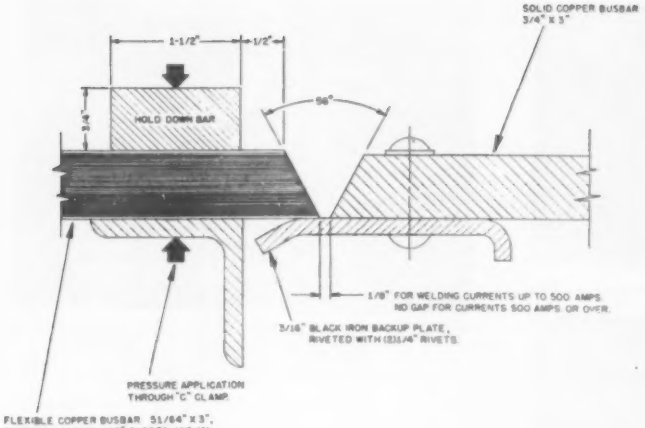
SOLID COPPER BUSBAR 3/4" X 3"
1-1/2"
1/2"
HOLD DOWN BAR
56°
1/8" FOR WELDING CURRENTS UP TO 500 AMPS. NO GAP FOR CURRENTS 500 AMPS. OR OVER.
3/16" BLACK IRON BACKUP PLATE, RIVETED WITH (2) 1/4" RIVETS.
PRESSURE APPLICATION THROUGH "C" CLAMP.
FLEXIBLE COPPER BUSBAR 51/64" X 3", COMPOSED OF (37) .020" SHEETS AND (2) .028" COVER SHEETS.

Fig. 19 Here is how the busbars are designed

which has gained rapid acceptance as an improved method for the fabrication of copper busbars. This application was developed following the successful introduction of sigma welding on aluminum busbars, and there is already an indicated use for over 100,000 lb. of copper wire on this application for new aluminum reduction plants. In Fig. 18 we see a welded assembly of 15 busbars prior to their removal from the welding jig.

Figure 19 illustrates the design of the busbar. The flexible section at the left is made up of 37 sheets of 0.020 in. thickness, and two cover sheets of 0.028 in. thickness giving a total thickness for the flexible section of $^{51}/_{64}$ in. The solid bar to which it is joined is $^{3}/_{4}$ in. thick. The joint is prepared with a 56 degree included angle of bevel and $^{1}/_{8}$-in. root spacing. The back-up strip is $^{3}/_{16}$-in. thick steel.

One of the steps in preparing the solid bar is shown in Fig. 20. The bars are band-sawed and then the wings are bent as shown in this view. Then fastening holes are drilled to complete the preparation of the solid bar.

Table 1—Physical Properties Which Can Be Expected with Commercially Available Sigma Electrodes as Compared to 6010 and 6012 Coated Electrodes

	*Tensile strength, psi.**	*Yield strength, psi.**	*Elongation in 2 in., %*	*Reduction of area, %*
E6010, E6011	62–73	52–61	22–28	35
Sigma weld with manganese-silicon killed rod	64–71	52–56	26–33	27–65
E6012, E6013	68–78	55–65	17–22	25
Sigma weld with manganese-silicon killed rod plus chromium	72–78	55–63	16–18	30–39

* Times 1000.

After the bars are prepared, the connector ends of the flexible bus are soldered, Fig. 21. On the left-hand side of this photograph, the workmen are separating the individual sheets. In the center, the assembly is being dipped in the molten solder bath. On the extreme right is a rack on which the bars are laid while still hot and drawn together with a C clamp. This completes the soldering job and eliminates any excessive solder.

The busbars are assembled in a welding jig. In Fig. 22 we see the welding jig with 15 assemblies inserted and ready for welding. Note the carbon blocks that separate the busbar assemblies. These blocks are used to prevent runout of the metal during the welding operation. Another close-up of the welded joint, and the preparation for welding, is shown in Fig. 23. Note that the $^{3}/_{16}$-in. steel back-up strip is riveted to the solid bus. This view also more clearly illustrates the

Fig. 20 One of the steps in preparing the solid portion of the busbar

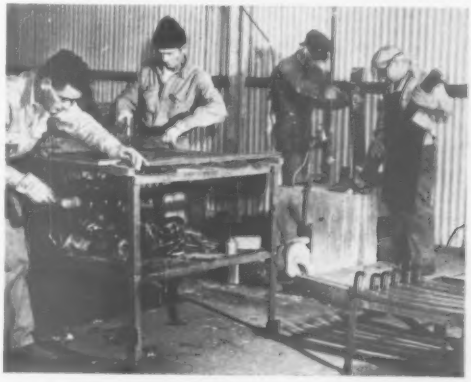

Fig. 21 Connector ends of the bus are soldered together

Fig. 22 Busbars assembled in the jig and ready for welding

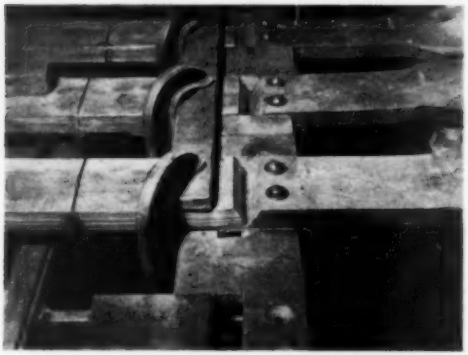

Fig. 23 Close-up of the joint. Carbon blocks separate the busbar assemblies and prevent runout of the metal during welding

carbon backing for the end of the weld. The length of joint is 3 in.

In Fig. 24 we see the welding operation in progress. Welding is accomplished with the manual sigma equipment. Direct-current reverse polarity at approximately 450 amp. is used. The welding rod is 372 Anaconda copper. The joints are preheated to approximately 600° F. by oxyacetylene heating. Welding time per joint averages about 1¼ min., or a total of 22 min. for the 15 assemblies.

SIGMA WELDING OF STAINLESS STEEL

In the field of stainless steel welding, there appears to be a broad potential field of application on materials ⅛ in. thick and over, and for some specialized automatic applications on material less than ⅛ in. thick. There is no loss of the stabilizing element in sigma welding, and the losses of other elements are less with the use of sigma argon than for other welding processes. Standard corrosion tests have been conducted on sigma welding of Type 347 steel and have shown that there is no difference in the corrosion rate between the material welded with straight argon and sigma argon, and that the corrosion rate in both cases is only a fraction of the maximum allowed.

One of the most extensive sigma welding applications on stainless steel involves the production of heavy-wall stainless steel pipe. A sketch of the pipe and weld-

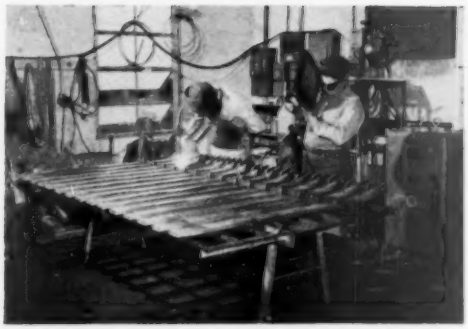

Fig. 24 The welding operation. Joints are preheated to about 600° F., by an oxyacetylene blowpipe

ing data is shown in Fig. 25. Pipe is welded in wall thicknesses ranging from ¼ to 1 in. One fabricator is now engaged in the production of approximately 55,000 ft. or over 10 miles of such pipe of 304 ELC and 308 composition. Note that for ⅛-in. wall thickness the pipe is welded in one pass with a 3/32-in. electrode at 20 in. per minute. For ⅜-in. plate, four passes are used at an average welding speed of 3½ ipm. of completed weld. The four passes are made without interruption as the welding head is reversed at the end of one pass, and the succeeding pass welded in the opposite direction. On this application the usual 5% oxygen mix of argon-sigma grade is reduced to approximately 1% by blending with pure argon. This mixture eliminates the oxide which would otherwise build up on the weld surface and require cleaning between beads.

Sigma Welding of Heavy-Wall Stainless Steel Pipe

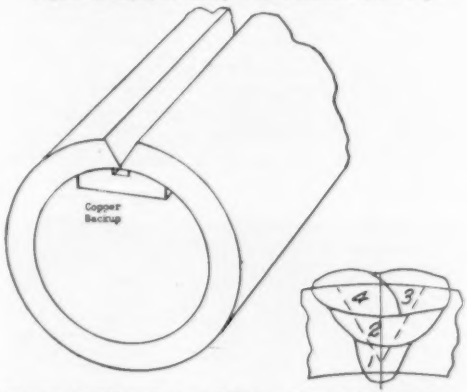

Fig. 25 Welding data and design for stainless steel pipe

Weld thickness in.	*Edge preparation*	*Backup groove in.*	*No. of passes*	*Current DCRP amps.*	*Electrode size in.*	*Welding speed ipm.*
¼	60° single vee, sharp nose	3/32 × 5/16	1	300	5/32	20
¾	50° single vee, 1/16 in. nose	1/16 × 1/4	1	375	5/32	12
			2	375	5/32	12
			3	375	5/32	16
			4	375	5/32	16

Note: 50 cfh argon, 1% oxygen.

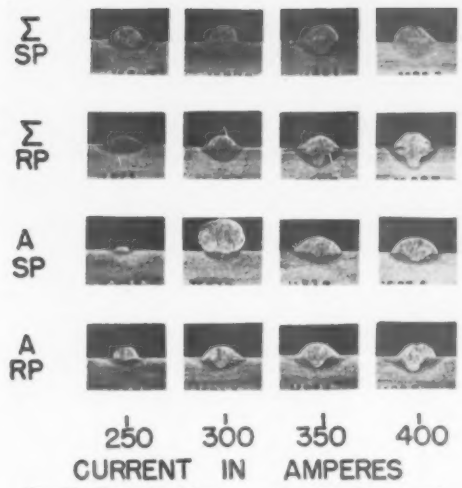

Fig. 26 Typical weld cross-section deposits in steel

SIGMA WELDING OF CARBON STEELS

Statistics indicate that over 95% of all electrodes consumed today in fusion welding are applied on steel and its alloys. The potential for sigma welding on steel, therefore, appears to be larger than on all other metals combined in spite of the fact that it may replace existing fusion welding methods only to a limited degree. Sigma welding undoubtedly costs more than submerged melt welding where the latter can be readily employed. On the other hand, even though it is applicable to welding in all positions, it is not as flexible as coated electrode welding and its economy in many applications will depend upon the maintenance of a higher operating factor due to the semiautomatic nature of manual sigma welding.

The elimination of flux, the ability to "see what you are doing" and the greater flexibility when compared to submerged melt welding may be the determining factors on some applications. The elimination of flux and particularly spatter, and the higher operating factor as compared to coated electrode welding may also justify the use of sigma welding in many applications.

On the basis of these assumptions, research and development investigations have been stimulated and some commercial application is being made. Table 1 gives the physical properties which can be expected with commercially available sigma electrodes as compared to 6010 and 6012 coated electrodes.

As has previously been mentioned, the discovery of argon-sigma grade has played a large part in the practical application of sigma welding to steel. It has also permitted the use of straight polarity with its advantage of less arc blow. Figure 26 illustrates typical weld cross-section deposits in steel using $^1/_{16}$-in steel electrodes at welding currents between 250 and 400 amp. and with argon and argon-sigma grade used with reverse and straight polarity. Note that with argon-sigma grade, the bead takes a usable form at lower current values than with straight argon. Note also the great difference in straight polarity between the bead formation with argon-sigma grade and straight argon. These comparisons illustrate why straight polarity can be effectively used in the sigma welding of carbon steel on some applications.

APPLICATIONS ON CARBON STEELS

One commercial application of straight polarity welding of carbon steel involves the fabrication of structural brackets of $^1/_4$-in. steel plate. The brackets are formed by fillet welding a T joint between the $^1/_4$-in. plate and the structure to which the bracket is attached. Welding in three planes is involved and straight polarity minimized the arc blow which would have been encountered with reverse polarity. Twelve manually operated sigma units are currently being used in production, consuming approximately 8000 lb. of steel electrodes per month. This application is replacing coated electrode welding on the basis of lower welding cost because of the high productivity of sigma welding on this application.

Figure 27 illustrates another sigma welding application on steel which will be placed in production with two machine setups as soon as the equipment is installed. Extensive trial in the manufacturer's plant has established lower welding cost than that possible

Fig. 27 Compressor housing fabricated by sigma welding

with the automatic light-coated metallic arc process now employed on the particular design of compressor housing shown. The complete elimination of flux with its attendant possible entrapment inside the welded joint was also a factor in the acceptance of sigma welding by this manufacturer. On this application argon-sigma grade, using $^3/_{32}$-in. electrodes and direct current reverse polarity at 380 amp., produced a welding speed on this $^3/_{32}$-in. lap weld of 55 ipm. The relatively large sigma electrode for welding on the $^3/_{32}$-in. thick base material is made practicable through the use of machine welding and electronic voltage control.

CONCLUSIONS

The commercial introduction of sigma welding as a whole is only slightly over three years old. In this short period of time many improvements have been made in the process, and its applicability to different metals. Even more important, in some respects are the improvements which have and are being made to the equipment and electrodes used in sigma welding. Research and development are isolating the numerous variables, and the relative importance of each in terms of both process and equipment requirements. Porosity control and elimination in weld metal in sigma welding, for example, appears to be more a matter of equipment than process or electrode.

In the next few years, we are going to see many additional improvements in the equipment and process. The process is still in its childhood. Even in its youth, however, it is firmly established on its own feet and growing rapidly and in good health. In the most competitive field of steel welding, sigma welding is going to assume a major role.

Problems and Equipment in Aircraft Spot Welding

Equipment used in the aircraft industries for resistance welding applications together with an indication of the advantages and limitations of each type

by J. R. Fullerton

RESISTANCE welding has enjoyed a swift rise to an important position in the aircraft industry within the past few years. Previously considered suitable only for joining secondary components because of its lack of capacity and uniformity, resistance welding is now being used extensively in the fabrication of all types of primary load-carrying structures. Reasons for this swift development are the greatly improved performance of modern equipment and the extensive backlog of experience which manufacturers, such as Ryan, have accumulated.

Undoubtedly, resistance welding is progressing rapidly in the aircraft industry. Its advantages are tailored to fit aviation's need; it is the fastest, cleanest method for joining weldable metals and, what is extremely important, adds no weight to many standard designs. A headless, invisible nugget of fused metal replaces the common rivet. It leaves aircraft surfaces smooth and clean with no protuberances to interfere with aerodynamic efficiency.

The Ryan plant contains 73 resistance-welding machines, including some of the largest and most modern facilities of their type. These consist of four main groups: (1) Three-phase, frequency-converter spot, roll-spot and seam welders; (2) three-phase, electrostatic, stored-energy spot and roll-spot machines; (3) three-phase, dry-disk, rectifier spot and seam welders; and (4) single-phase, alternating-current spot, seam and spot-tack machines.

Unlike many commercial manufacturers, who use spot welding for a limited number of materials and fairly standard applications, Ryan employs this technique for a wide variety of metals and designs. In

J. R. Fullerton is with the Development Laboratories of the Ryan Aeronautical Co.

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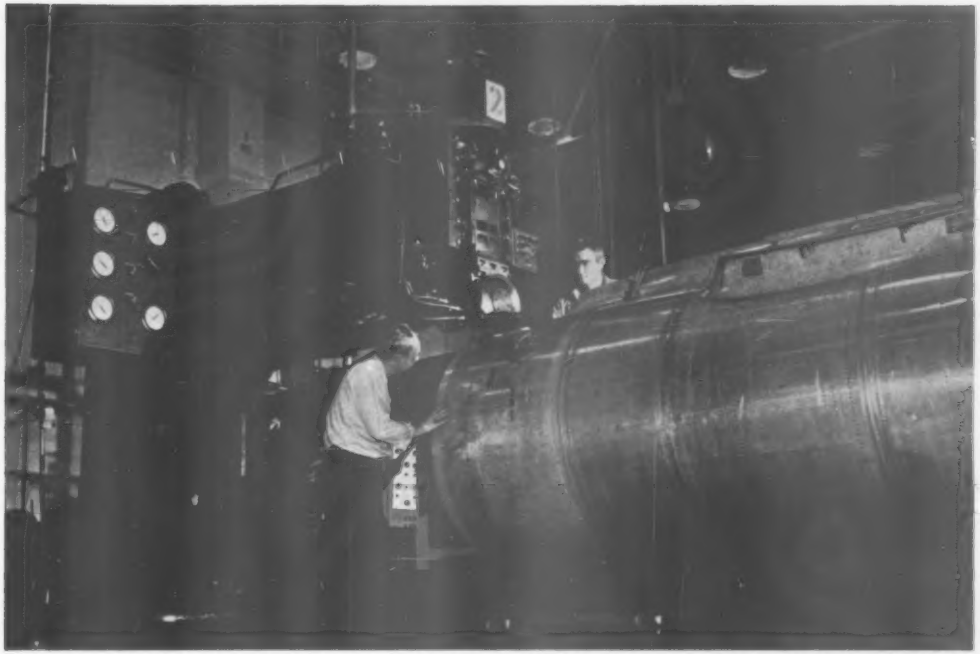

Fig. 1 Ryan three-phase, frequency-converter welding machine used to fabricate world's largest external fuel tanks for aircraft. Designed and built especially for this type of production, these are the largest welders in the country

addition to the aluminum and magnesium alloys commonly used in aircraft work, our fabrication includes the various stainless steels, such as Types 347, 321, 302, 310, 410 and 19–9DL, the mild steels and the more difficult metals of titanium, Inconel, Inconel X, Rosslyn Metal, Haynes-Stellite X-155 and Armco 17–14 CuMo.

These materials are employed both in airframe applications where strength and light weight are paramount considerations and in jet, rocket and piston engine components where resistance to heat and corrosion at high temperatures is a vital requirement. Most of these applications place important responsibilities upon resistance welding because structural failure can result in loss of life.

With such variety of materials, gages and designs, Ryan resistance-welding facilities must be comprehensive and versatile. Each product presents a specialized problem to be analyzed in terms of equipment, joint efficiency, economy and service life. Ryan facilities are capable of performing every task within the industry's scope from the simple tack welding of stainless steel exhaust manifolds to the production of the world's largest external fuel tanks for aircraft.

However, every resistance-welding machine has limitations both as to capacity and flexibility. Therefore, one of the most important considerations of a successful program of resistance welding is the selection of the equipment. Careful balance must be maintained between the types of machines used. Facilities have become so specialized that it is mandatory that each machine be purchased with specific types of materials, gages and designs in mind, providing for versatility

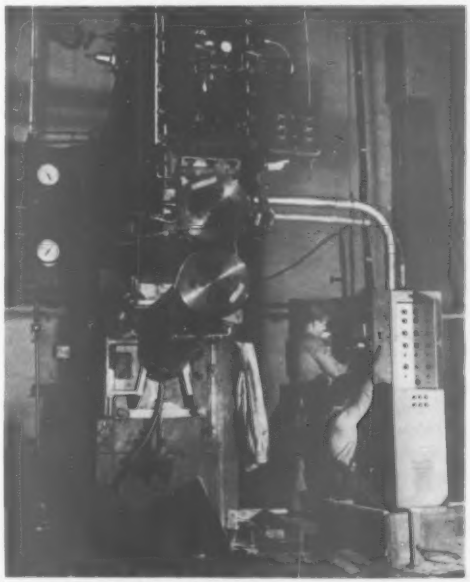

Fig. 2 Three-phase, frequency-converter welding machine being installed at Ryan Aeronautical Co. plant for Production of Ryan external fuel tanks for aircraft

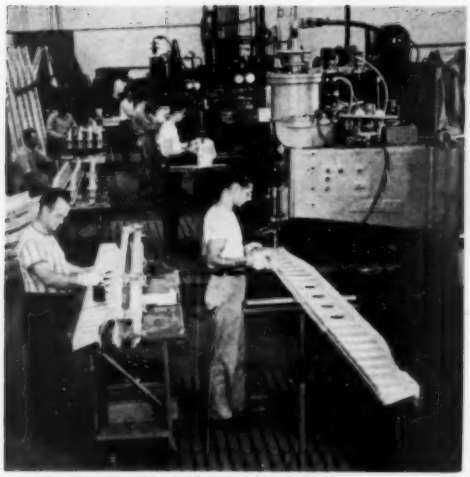

Fig. 3 Ryan's three-phase, electrostatic stored-energy spot-welding machines used exclusively for fabricating aluminum alloys. Excellent for attaining long tip life, minimum distortion and constant power. Here, they are used to build floor beams for Boeing C-97 Strato-freighters

as far as possible. Provisions for new, future developments should be made by selecting equipment which lends itself to improvement and expanded utilization. The above is not intended to advocate purchase of new equipment for each new job but to emphasize the point that all new equipment should be adaptable to future anticipated work wherever possible.

Ryan's manufacturing operations are concerned with two general classes of metals of quite different characteristics—heat- and corrosion-resistant alloys and the light alloys. During World War II, extensive fabrication of secondary aluminum structures was accomplished by use of stored-energy type machines. Successful structural welding of heavy-gage aluminum alloys was not performed in aircraft until more modern welding machines, capable of delivering higher currents and exerting heavier forging pressures were designed. Today, "crack-free" structural welds in 0.125 24ST Alclad are not only practical but common. This is due not only to improvement in controls but also to development of larger machines, improved pressure systems and improved welding techniques and process controls.

In the case of the stainless steels, resistance welding of structural components was accomplished early but the scope of this process has expanded with the growth of the jet engine program. The stainless steels lend themselves well to resistance welding techniques. Many of these alloys, such as Inconel X, Inconel W, 4130, 410 and 1020, are heat treatable. This necessitates special pre- and postheating accessories or the use of heat-treating furnaces to temper the weld area to avoid cracking after welding.

With these alloys, we encounter narrower edge distances and overlaps due to the weight requirements of aeronautical components. Another problem is the expanding use of mixed alloys in a structure so that different melting points and electrical resistances may exist between continuous sheets, thus presenting heat balance problems.

Our utilization of the four basic types of machines mentioned previously is discussed hereafter.

THREE-PHASE FREQUENCY-CONVERTER MACHINES

Included in our group of three-phase, direct-demand machines are some of the largest of this type. These were selected for both production use and developmental purposes. Every accessory purchased with them was intended to fit them for all types of work with steel and aluminum alloys and for use in experimental investigations. Our large machines are rated at 120,000 amp. short circuit current and 11,000 lb. electrode force. This potent power can perform continuous, crack-free structural welds in two sheets of 0.187-in. steel or 0.125-in. aluminum, to exacting military specifications.

These machines have excellent versatility. We use them for production of welding of such varied materials as titanium, Inconel, Inconel X, stainless steel, Types 310, 302, 347, 321, 410, L-605 and mild steels. All resistance welding of aluminum alloys is now confined to either these machines or our three-phase, electrostatic, stored-energy type.

It is fair to say that the development of the electronic controls has made modern resistance welding successful.

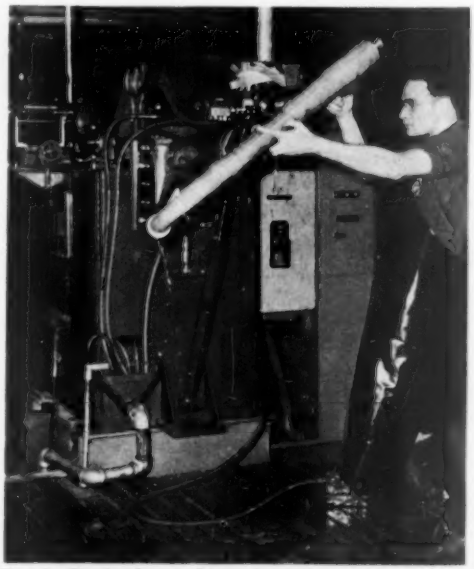

Fig. 4 Single-phase, alternating-current seam-welding machine used to seam weld flanges on stainless-steel headers for Pratt and Whitney aircraft engines

and nowhere is this better exemplified than in the complex electronic controls of this equipment. We have precision control over wave-shape, time and pressure cycles in these machines. In the year in which we have been working with this equipment, we feel that we have not explored all of the possibilities for production which these controls, with their many variables, have presented. We have learned a number of basic fundamentals which underlie the successful operation of this equipment and further experience will probably demonstrate even greater versatility.

We feel that the three most important problems requiring concern in utilizing these machines are maintenance, electrode life and pickup, and sensitivity to power variation. The maintenance problem is a natural outgrowth of the increase in number and complexity of circuitry. We find that our concern for this problem is lessening as our maintenance personnel become more familiar with the equipment and its functions. However, the machines demand a higher caliber of maintenance personnel and greater diligence to the understanding of the work.

In spite of the reports that these machines have been improved in the matter of electrode life and pickup, we find that there is still need for further work in this field. Probably the complete solution of this problem, in the case of aluminum alloys, will come only when shorter weld times are possible.

Sensitivity to power variation is a typical phenomenon related to direct demand equipment and is held within acceptable limits by proper engineering of the power supply to meet machine characteristics.

Our largest frequency-converter machines have a throat depth of 60 in. and a 62-in. working height. They were designed with the objective of building the Ryan external fuel tank in mind. This huge fuel container is formed into a smooth cell with spot- and seam-welded joints without the use of rivets or sealing compounds. Thirty thousand spot welds are used in its exterior skins. The big spot- and seam-welding machines have proved eminently satisfactory in the tough assignment of fabricating large quantities of these structures without rejection.

THREE-PHASE ELECTROSTATIC STORED-ENERGY MACHINES

The electrostatic, stored-energy type equipment is a popular performer at Ryan. We have spot, seam and roll-spot machines which are accomplishing excellent work in spite of their vintage. The limitations on this equipment are restricted speed for seam welding and confinement to use with aluminum and magnesium alloys because of wave shape. Of course, special cross wire, projection, and similar applications of welding with other materials can be accomplished but these are not classified as structural aircraft jobs.

The advantages of these machines are numerous. They are insensitive to power variation, possess

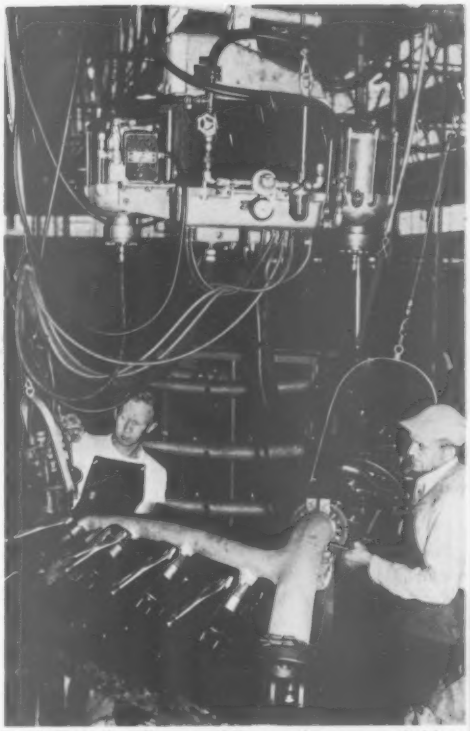

Fig. 5 Twin "gun" spot-welding machine suspended from overhead conveyor. This is a single-phase type used to obtain good spot welds in this Pratt and Whitney exhaust system where access to the flanges is a factor

long tip life, perform with minimum distortion and provide excellent duplication of specified results. We are using them for making crack-free structural welds in 24ST Alclad in thicknesses running to 0.081 in.

A striking example of the type of work which these machines perform is the large floor beam built for Boeing C-97 Stratofreighters. One thousand spot welds are placed in each of these lightweight structures to form an I-beam assembly which is part of the structural floor of the Stratofreighter. Forty-nine of these beams go into each C-97, which can transport 68,000 lb. of freight.

THREE-PHASE, DRY-DISK, RECTIFIED MACHINES

The dry-disk rectifier machines are new additions to the Ryan plant. They were purchased to supplement our single-phase equipment and will be utilized for welding stainless steels, nickel alloys and similar metals. This type of equipment has been successfully used by many other manufacturers for aluminum alloy work with excellent results, but we have installed it for production work with stainless steels only. Consequently, it does not incorporate those features normally required for aluminum welding.

Fig. 6 Bank of single-phase spot-welding machines used at Ryan to "spot-tack" stainless-steel half-stampings into alignment prior to seam welding operations

The outstanding characteristic of the new dry-disk machines is their simplicity of control, which will permit the minimum of maintenance. As we accumulate experience in the use and maintenance of the rectifier type, we feel certain that the machines will become popular in our plant.

We will use this equipment for the fabrication of jet, rocket and piston engine components of high-temperature-resistant steels, Inconel and other special alloys. Such assemblies as combustion chambers, transition liners, exhaust cones, tail-pipes, and manifolds will be welded on these facilities.

SINGLE-PHASE, ALTERNATING-CURRENT MACHINES

Our single-phase equipment is the basic "workhorse" of the steel welding group and has been for many years. These machines have performed well in the fabrication of stainless steels, nickel alloys, low-carbon steels and titanium and will continue to prove valuable in this work. With the present trends toward heavier gage materials and new designs, accessory equipment is being added to many of the machines, to widen their capacity. In a number of instances, newer machines of the three-phase type have taken over the jobs which required greater versatility.

At Ryan, the only accessories which we have used with this equipment have been those providing slope control, postheat and roll-spot facility.

The basic reasons why the single-phase machines are classed as our primary steel welding tool are their reliability, availability, simplicity and low cost. Large numbers of these machines have been used in aircraft work and are readily available for the expanding program made necessary by the advent of the jet power plant. The machines are simple in design and the controls with the addition of accessories provide a reasonable amount of versatility. Standard accessory controls, such as slope control, postheat and pulsation type panels, adapt these tools to many different tasks. Then the low initial cost of single-phase equipment as compared with three-phase, is a strong incentive to their use in any plant or shop.

We are aware of the inroads which the new, three-phase machines are making into the steel fabrication work and have a large number of these machines in our plant. With their higher power factor, balanced loading and lower demand characteristics, they are replacing single-phase equipment in many categories. Their adaptability to different materials is also a strong factor in their popularity. However, this does not mean that the single-phase equipment has been rendered useless in the aircraft industry and we are making comprehensive use of the latter in the work for which it is suited or adaptable.

We have utilized a number of interesting portable welding machines, of the single-phase type, which are used with designs where accessiblity is a problem. Many of these are overhead, suspended models. It is not surprising to find portable equipment which meets or exceeds the military specifications on steel thicknesses which were considered ceilings on stationary facilities during the recent war. Credit for this achievement should go to the equipment manufacturers and commercial welding plants who have pioneered in this special development thus making available standard designs for utilization on aircraft joining problems.

ACCESSORIES

We believe that certain accessories are a must for use with resistance-welding equipment in an aircraft factory. These are as follows:

Slope Control

As we use it, this accessory is an appreciable aid in welding tasks where extreme thick-to-thin ratios and minimum edge distances are prevalent and where reduced electrode pressures are mandatory. It is also valuable in handling materials which exhibit a tendency toward excessive "spitting."

Pre- and Postheat Controls

These controls are almost mandatory when heat-treatable steels are welded. They may be used in the same manner as slope controls with reasonable success and may also be utilized for many different pulsation welding effects.

Often, the addition of either slope or pre- and postheat controls will permit a smaller welding machine to accomplish a job that would otherwise require a machine of greater capacity.

Deflection Firing

This feature, found on many World War II machines, is a necessity, in our opinion, on equipment used to weld aluminum alloys. It consists of a resilient member, incorporating a dial indicator, microswitch and micrometer adjustment. Located between the electrode and pressure members of the machine, it is calibrated in pounds of electrode force. When properly set, it permits the current to flow only at the exact pressure desired and is much more accurate in this function than using gages which indicate air pressure at a point distant from the actual work. A properly designed deflection firing system will cut welding current when pressure drops, prevent firing under light pressure, provide increased control with less maintenance over pressure system and monitor the electrode pressure throughout the complete welding cycle.

Fixed-Increment Heat and Timing Adjustments

We favor the use of appropriately small fixed increment adjustments for heat and timing control because it gives us better opportunity to duplicate work with exactness. This is a matter of individual opinion and may not be important in plants where duplication work is not a factor.

Roll-Spot Devices

This accessory has been found to be most useful in seam welds and spaced spot welds where accessibility permits its use. It steps up production rates and assures accurate spacings. Many new designs are being developed to utilize roller electrodes on spot welding and this accessory is a must for economical production on jobs permitting its use.

Reduced Heat First Spot

This device automatically reduces the heat of a first spot weld in a set up and compensates for the "shunt effect." It eliminates splash and cracking in critical assemblies and its cost is repaid in savings on rejections and reduced reworking.

Series-Parallel Tap Switches

These devices save time in setting up major change-over jobs in large machines. A series-parallel transformer tap system is a necessity where fine heat control is desired and a wide range of work is to be accomplished.

Unipolarity, Plus or Minus Firing

This facility, available on some machines, is employed at Ryan where analysis indicates that uniform penetrations in sheets of different thicknesses can be obtained by utilizing the "drift" due to direction of welding current. This "drift" has often been an important factor in obtaining proper heat balance.

Relatively few of the possibilities which modern resistance-welding equipment and new techniques offer have been realized. If recent years are a guide to the future, design engineers, production experts and research analysts will continue to uncover metal joining applications which this process can perform with greater speed and economy than any other.

New Austrian Welding Standards

by Hans Melhardt

THE third section of Austrian Standard B4300 deals with the design and construction of welded steel structures. Together with Section 2 on riveted and bolted structures and Section 7 on qualifications of welding engineers and operators, Section 3 completes a unified specification. It is not a copy of specifications in force in other countries, but is a new document representing latest welding developments with particular reference to Austrian conditions. There was a desire on economic grounds to raise allowable stresses in view of new information[1] developed since the preparation of this specification was begun[2] in 1945. These increases have been justified only if definite safety measures are taken from the standpoints of material, design and workmanship. From the material standpoint the two questions of hard zones and brittle fracture have been studied. From the design standpoint particular study has been made of the strength of welds of different shapes made with different types of welds and different degrees of care.

MATERIALS

The present specification adopts the steels of Austrian Standard M3115 (Bridge and Structural Steels, Special Quality T) shown in Table 1. The letter T signifies that the steel must pass the weldability tests of Tables 2 and 3, and must contain 0.20% C max., 0.060 P max., 0.060 S max., 0.10 P + S max., and for St 52T 0.60 Si max. Austrian Standard M3050 (Tensile and Bend Tests for Welds) will be issued soon. The bead-bend test of Austrian Standard 3052 is a modification of the Komerell test to reduce the expenditure of material and time of preparation, without reducing the ratio of bead cross section to specimen cross section required for a severe test. The requirements for the bead-bend test are given in Table 4 and Fig. 2. The specimen passes if it exhibits a ductile fracture. If the fracture is brittle or partly brittle, the bend angle given by Curve *B*, Fig. 2, must be attained. The last requirement is believed to be reasonable because steels exhibiting a large bend angle before brittle or partly brittle fracture need not be termed "unweldable."

Up to 1942 about 150 railway bridges and 450 highway bridges were welded in Germany using low-alloy steel St 52. There were only two mishaps:[3] the Zoo railway bridge in Berlin, and the Rüdersdorf highway bridge. A thorough study of the mishaps showed that the weldability of a steel depends more on its melting and deoxidation than on its alloy content.[4] Of course, weldability is an ill-defined term.[5] The International Institute of Welding defines three grades of weldability: ordinary, good and high. We have attempted to replace the bead-bend test by other tests, particularly the notch impact test. However, any test not in-

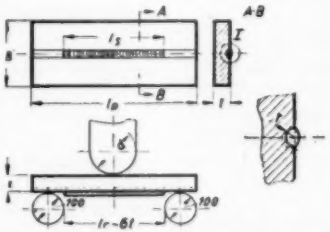

Fig. 1 Bead-bend test specimen. Rollers are 4 in. in diameter

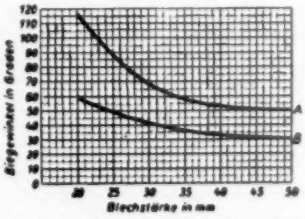

Fig. 2 Bend angles required for plates of different thicknesses in the bead-bend test

Vertical scale: bend angle, degrees. Horizontal scale: plate thickness, mm. (50 mm. = 2 in.). Curve *A*—Minimum bend angle for ductile fractures. Curve *B*—Minimum bend angle for brittle or partly brittle fractures

Abstract of "Die Önorm B4300/3," published in *Schweisstechnik*, **6**, 1-7 and 21-36 (1952). (Abstracted by Dr. G. E. Claussen.)

Table 1—Mechanical Properties* of Unwelded Steels Required by the Specification

		Thickness of the rolled steel, in.							
		0.20 to 0.32	*Over 0.32 to 1.18*	*Over 1.18 to 1.97*	*0.20 to 0.32*	*Over 0.32 to 1.18*	*Over 1.18 to 1.97*	*Bend test (bend angle must equal 180°)*	
Type of steel	*Tensile strength, psi.*	*Yield strength, psi., min.*			*Elongation % in 5 diameters*			*Plate thickness in.*	*Pin diameter†*
St 37T	52,500–64,000	31,000	31,000	28,500	22	25	22	≤0.79	0.5*t*
								≦0.79	1*t*
St 44T	62,500–74,000	37,000	37,000	34,000	21	24	21	≤0.79	1*t*
								≦0.79	2*t*
St 52T	74,000–91,000	51,000	47,000	43,000	19	22	19	≤0.79	2*t*
								≦0.79	3*t*

* The mechanical properties apply to steel as-received. Plates and flange plates must be normalized as follows: St 52T in all thicknesses, St 44T over 1 in., and St 37T over 1.18 in. thick.

The following values are for design purposes: modulus of elasticity =30,000,000 psi., shear modulus = 11,500,000 psi., coefficient of thermal expansion per ° C. = 0.000012.

† *t* = plate thickness. The maximum thickness for Standard B4300 is 1.18 in.

Table 2—Weld Tests Required by Standard M3115

Type of steel	Thicknesses requiring a weld tensile test,* in.	Thicknesses requiring a weld bend test, in.	Weld bend test*: Pin diameter†	Bend angles (degrees) for a plate thickness of: Up to 0.59 in.	Over 0.39 to 1.18 in.	Over 0.79 to 1.00 in.	Over 1.00 to 1.18 in.	Thicknesses requiring a bead-bend test,‡ in.
St 37T	Up to 1.18	Up to 1.18	2*t*	120	120	90	90	Over 1.18 to 2.00
St 44T	Up to 1.00	Up to 1.00	3*t*	120	90	60	..	Over 1.00 to 2.00
St 52T	Up to 0.79	Up to 0.79	3*t*	90	60	..	..	Over 0.79 to 2.00

* Austrian Specification 3050. Both tensile and bend specimens are 1.18 in. wide, 12 in. long.
† *t* = plate thickness.
‡ Austrian Specification 3052, see Tables 3 and 4 and Figs. 1 and 2.

Table 3—Dimensions (In.) for the Bead-Bend Test, Figs. 1 and 2, Standard M3052

Plate thickness, *t*	Length, *lp*	Width, *b*	Groove diameter, 2 × *r*	Length of weld, *la*	Diameter of electrode, in.	Pin diameter, *d*	Distance between rollers, *lr*	Welding current, amp.
0.79–1.00	13.8	5.9	0.24	4.9	0.16	2.9	5.5	160–190
1.00–1.18	15.0	5.9	0.24	5.9	0.16	3.5	6.5	160–190
1.18–1.38	16.2	5.9	0.24	6.9	0.16	4.1	7.5	160–190
1.38–1.58	17.3	7.9	0.32	7.9	0.20	4.7	8.7	210–240
1.58–1.77	18.5	7.9	0.32	8.9	0.20	5.3	9.9	210–240
1.77–2.00	19.7	7.9	0.32	9.9	0.20	5.9	11.0	210–240

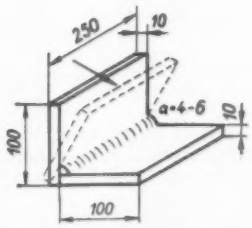

Fig. 3 Fillet break specimen

Dimensions in millimeters. Plates are ¾ in. thick, the weld is 10 in. long to be made with one change of electrodes. The specimens for covered and cored electrodes must have 0.16-in. throat for horizontal fillets and 0.20–0.24-in. throat for vertical fillets.

The requirements for the weld, including the location of change of electrodes are: (1) The legs must be equal and the contour must merge smoothly with plate. (2) The weld appearance and throat thickness must be uniform. (3) Fracture must occur entirely in the weld. (4) Fracture must show complete fusion, no slag inclusions and no porosity

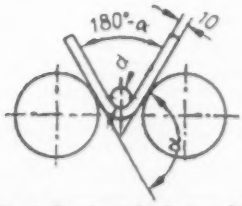

Fig. 4 Bend test for butt welds in ¾-in. plates

Pin diameter, 0.79 in. for St 37T and 1.18 in. for St 44T and St 52T. Bend angle (minimum), 120° for St 37T and St 44T and 90° for St 52T with covered electrodes. Bend angle (minimum), 120–90° St 37T and St 44T and 90–60° for St 52T with cored electrodes. The lower value is permissible if the fracture appearance is clean for cored electrodes

Table 4—Characteristics of Bead-Bend Fractures, Standard M3052

Type of fracture	Progress of fracture	Appearance of fracture	Minimum bend angle
Ductile	Gradual until full fracture	Dull and fibrous	Curve *A*
Partly brittle		Partly crystalline Partly fibrous	Curve *B*
Brittle	Sudden over the entire cross section	Crystalline	Curve *B*

volving welding does not seem capable of indicating the behavior of the steel in the welded condition. In my experience bead-bend results are reliable, while it is difficult to decide anything from notch impact values, which generally scatter a great deal. Tests by Folkhard[6] support this experience.

The effect of low temperature in increasing the tendency to brittle fracture is well known. As a matter of fact, both Zoo and Rüdersdorf mishaps occurred in very cold weather. However, the stress caused by the low-temperature contraction of the steel might have exerted some effect. It is still a question whether the bead-bend test should be conducted at low temperatures. The development of the Aldur steels, which have good weldability and little tendency toward brittle fracture at low temperatures, is a very important factor toward preventing brittle fractures in Austrian welded structures.[7] By way of summary, we may say that the bead-bend test (Standard M3052) was a valuable addition to Standard M3115, which has been adopted in B4300/3 with the additional limitation in plate thickness to 1.18 in.

ELECTRODES

Only those covered or alloy-cored electrodes may be used that can produce welds having at least as high tensile strength as base metal, Table 1. The welded joint is tested in accordance with Standard M3050. Bare or thin coated electrodes may be used for manual welding only for those joints whose failure could have no serious consequences for the structure. They may be used for submerged arc automatic welding or for welding under a protective gas (argon-arc) provided the remaining requirements of this section of the specification are met.

The static test requirements for electrodes are:

1. Tensile test of a welded joint in accordance with Standard M3050. The welded joint must have the same or higher strength than base metal.
2. Fillet weld fracture test in accordance with Standard 4300/7, Fig. 3.
3. Bend test of a butt weld in accordance with Standard 4300/7, Fig. 4.
4. Usability test in vertical and overhead positions, Fig. 3.
5. Hot crack test, Fig. 5. After the

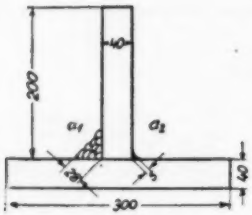

Fig. 5 Hot-crack test specimen in 1.57-in. plates. Dimensions in millimeters

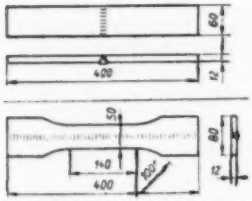

Fig. 6 Fatigue test specimens in 1/2-in. plates. Dimensions in millimeters

heavy weld a_1 (1.10-in. throat) is deposited on one side of the fillet, the specimen is cooled to room temperature. Test weld a_2 then is deposited with the test electrode in a single layer. No cracks must appear with magnaflux or equivalent testing. The hot cracking test is in the specification because many covered electrodes, particularly the fluid iron-oxide types, are excellent in butts but tend to hot crack in fillets. The best electrodes in the hot crack test are austenitic chromium-nickel steel electrodes and alloy-cored electrodes, which deposit weld metal insensitive to notch effect.

The fatigue test specimens for electrodes are shown in Fig. 6. The specimens must not be peened nor heat treated after welding. The lower tensile stress is 1420 psi. Unmachined transverse specimens of St 37T must withstand two million cycles at an upper tensile stress of 23,500 psi. Transverse specimens with the weld machined flush with the surface must withstand two million cycles at an upper tensile stress of 28,000 psi., while the longitudinal weld specimens must withstand two million cycles at an upper tensile stress of 25,800 psi. Requirements for St 44T and St 52T have not yet been determined. At least three specimens of each type must be tested. The German specifications for welded plate girder railway bridges required only 20,000 psi. fatigue strength for the unmachined transverse butt weld specimen at two million cycles. Folkhard,[8] in the laboratories at Linz, obtained an average fatigue strength of 26,000 psi. (lower stress = 1400 psi.) for welds in St 37. Both German and Swiss authorities adopt 1.25 as the ratio of required pulsating tension fatigue strength to allowable pulsating tensile fatigue stress for design. The same value for the ratio is adopted in the Austrian specifications.

Table 5—Permissible Stresses Under Static Loading

	Type of stress	—Permissible stress, psi.— St 37T	St 44T	St 52T
Base metal and butt welds	Tension, compression, bending	20,000	24,000	30,000
Base metal and butt welds	Shear	11,900	14,400	18,000
Fillets (based on throat)	Tension, compression, bending	13,900	16,800	*
Fillets (based on throat)	Shear	13,900	16,800	*

* Yet to be determined from tests.

WORKMANSHIP

There are two principal factors in workmanship. First, the technical factor consists in developing sound procedures, which do not call for excessive effort on the part of the operators. Second, the instructional factor comprises selection, training, supervision and testing of the operators. In the present specifications no use has been made of the German and Swiss "first-grade" and "second-grade" welds. The rules for butt welds are:

1. The root of the butt must be either ground out and welded from the reverse side, or full penetration must be secured from one side by using a grooved copper backing followed by grinding the under side of the weld flush with the plate.
2. Craters are not allowed at the end of a joint, because they reduce fatigue strength.
3. The sides of a weld should be ground so as to secure freedom from notches. The grinding may be as deep as 5% of plate thickness to remove undercut.
4. The reinforcing beads should be only high enough to assure freedom from porosity and undercut.
5. All welds designed for a fatigue stress more than 70% of the allowable fatigue stress must be radiographed for cracks, incomplete fusion to the side walls, slag inclusions and porosity. Defects perpendicular to the fatigue stress are particularly dangerous.

The rules for workmanship of fillet welds are:

1. The junction of weld with plates must be free from irregularities such as undercut. The weld should have equal legs and flat contour if it is parallel to fatigue stress. If it is perpendicular to the fatigue stress, the weld should have that leg lying in the direction of stress as long as possible.
2. The weld must be free from holes and cracks as revealed by a hand magnifier. For important welds magnaflux may be required.
3. Craters must not be allowed at the ends of a joint.
4. The leg of normal fillets that is in the plane of stress should be twice the throat plus 1/8 in.

PERMISSIBLE STATIC STRESS

The permissible stresses under static loading are given in Table 5. The values for small (throat less than 0.34 in.) and large normal fillets (throat over 0.55 in.) should be[9] reduced 5 to 20%. Under some conditions all values may be raised 15%. For butt welds in plate girders only 85% of the values in Table 5 should be used due to uncertain quality at the web-flange junctions.

PERMISSIBLE FATIGUE STRESS

The data and methods of Roš[1] are used with some modifications. His methods are based on four factors:

1. The ratio of A, the smallest stress to B the largest stress.
2. For different values of A/B the fatigue strength is derived from the results for $A/B = 0$.
3. For multiaxial stress the comparison stress ($= \sqrt{S_x^2 + S_y^2 - S_x S_y + 3T^2}$) is used.
4. Account is taken of the different strengths of welded joints under transverse, longitudinal and shear loads by α factors.[10]

The permissible values for fatigue strength based on these factors and on tests results of Roš are given in Table 6.

Table 6—Permissible Fatigue Strengths for Butt Welds

St 37T = 20,000 × 1/G,* psi.	A/B	St 44T = 24,000 × 1/G,† psi.
24,000	+1.00	28,200
22,600	+0.75	25,500
21,400	+0.50	24,500
20,000	+0.25	22,600
18,500	0.00	20,800
17,100	−0.25	19,000
15,700	−0.50	17,200
14,400	−0.75	15,600
13,000	−1.00	13,500

* $1/G = 0.93\,(1 + 0.30\,A/B)$.
† $1/G = 0.87\,(1 + 0.35\,A/B)$.

QUALIFICATION OF WELDING OPERATORS

The operator for welding steel structures must meet the following requirements of Austrian Standard B4300/7:

1. Must have attended and passed the examinations of a welding school.
2. Must have at least one year's experience in general steel construction.

3. Must pass the qualification tests of this specification.
4. Must always be in practice.

Concerning the first requirement, the general schooling program in Austria consists of (*a*) basic schooling, (*b*) 600 hr. shop practice in welding and (*c*) further instruction to perfect the applicant's knowledge. Qualification tests consist of a butt weld 12 in. long and a fillet weld 10 in. long, both in $^3/_8$-in. plates. The butt is radiographed and used for tensile and bend tests. The fillet weld is made in the horizontal or vertical position. The fillet is examined for uniformity and size and is broken for examination of fracture.

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1. Roš, M., *Schweisstechnik Sonderheft*, 1948, and *Revue de Métallurgie*, 1948.
2. Melhardt, H., *Schweisstechnik*, Heft 1 and 2 (1949).
3. Komerell.
4. Werner.
5. Rapatz, F., *Berg-und Hüttenmännische Monatshefte*, 1950, Heft 12, Sonderheft IMST, Leoben (1950); see also the article by Legat in the same issue.
6. Folkhard, *Voest Jahrbuch*, 1951.
7. Hauttmann, *Berg-und Hüttenmännische Monatshefte*, 1950, Heft 12, Sonderheft IMST, Leoben (1950); see also the article by Legat in the same issue.
8. Folkhard, *Schweisstechnik*, Heft 8 (1948).
9. Melhardt, H., *Ibid.*, Heft 4 (1948).
10. Melhardt, H., *Ibid.*, Heft 5 (1948); see also ref. 5.

PRACTICAL WELDER AND DESIGNER

Fourteen Hundred Dollars Saved in Eight Hours

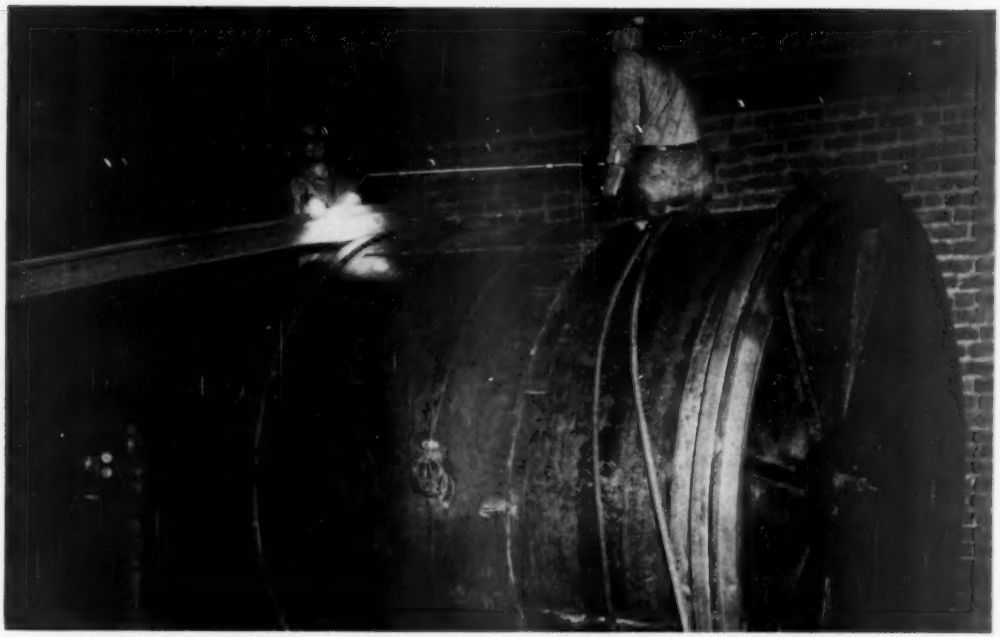
Three-month tie-up—$60 per hour—rental loss prevented by Metallizing

THE 14 ft long by $6^1/_4$ in. diameter solid Monel shaft, shown being sprayed with stainless steel, is used on a tugboat in service around New York harbor where it commands a rental of $60 per hour. The shaft had become badly worn at the stern packing, causing serious leakage. With nickel in critical supply, at least two to three months would have been required for delivery of a new Monel shaft stock and an additional week to machine it, at a cost between $1200 and $1400. However, even this high price would be far overshadowed by the loss of many thousands of dollars of rental revenue over a 2 to 3 month period.

Of course, ordinary forged steel stock could be used to fabricate a new shaft and could probably by obtained in 2 to 3 weeks at a cost of about $1000. But past experience showed that the life of ordinary steel in this service would be only about one quarter of that of Monel.

On the other hand, application of metallized stainless on Monel in service like this actually extends the life of the shaft because of the improved lubricating characteristics of sprayed metal.

This is how the job was done. The worn portion of the shaft at the stern packing area was turned down in the lathe to $6^1/_8$ in. diameter and prepared with a special roughening tool. Next, about 8 lb of stainless steel was sprayed to bring the diameter to $6^5/_{16}$ in. and the shaft was then turned to the required $6^1/_4$ in. diameter. Total time for the entire operation was 8 hr and the tugboat was back in service in two days.



Heating with the Oxyacetylene Flame

Hundreds of bending, straightening, and forming operations can be done with the oxyacetylene flame

by Earl H. Frail

THE intense, localized heat of the oxyacetylene flame makes it the best method of heating for many forging, forming, straightening, and bending operations. It is fast, easy to control, economical and convenient. With the flame, heat can be applied exactly where it is needed and overheating is easily avoided.

EQUIPMENT NEEDED

For many heating jobs on angle iron, strap iron, small diameter pipe, and sheet metal, a welding blowpipe with a large size welding tip with the flame adjusted to neutral will do the job. However, when the metal is more than about $^1/_4$ in. thick, when large diameter pipe is being bent, or when forging or forming operations are being done on heavy material, special multiflame heating heads get plenty of heat into the metal quickly. These heavy-duty heating heads, which can be obtained from your welding supplier are shown in Fig. 1. They give the operator an easily-controlled flame of approximately 6000° F.

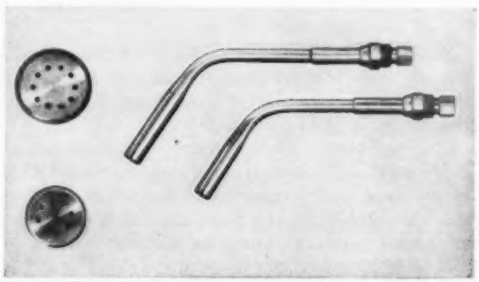


Fig. 1 These heavy-duty heating heads provide plenty of heat and speed up preheating, bending and forming jobs. The sketches show the end of the heads

Earl H. Frail is connected with the Linde Air Products Co., New York, N. Y.

Fig. 2 Bent or twisted parts can be straightened by heating, then hammering to the proper shape

CHART OF PRACTICAL APPLICATIONS

The basic operations for a number of heating jobs are illustrated. Twelve sketches of common jobs show where and how to use the oxyacetylene heating flame to get best results. By applying the principles illustrated in these simple sketches, an operator can handle easily the more complicated work as it comes along.

Some of these principles are shown in the typical jobs illustrated in the photographs.

SOME STRAIGHTENING JOBS

Metals are usually easier to bend, form, or straighten when they are heated. By the use of heat and a hammer, the binder wheel, shown in Fig. 2 was straightened.

The heat of the oxyacetylene flame is also used to advantage in several convenient and laborsaving methods for bringing a bent or warped shaft back into alignment. A common procedure for shaft-straightening is to set up the shaft in a lathe and rotate it in order to find the bent section. When this is determined, the outside of the bend is positioned at the bottom and heated with the blowpipe as shown in Fig. 3(A). Pressure is then applied to the heated area with a crowbar blocked up on the lathe bed to force the warped section back into line.

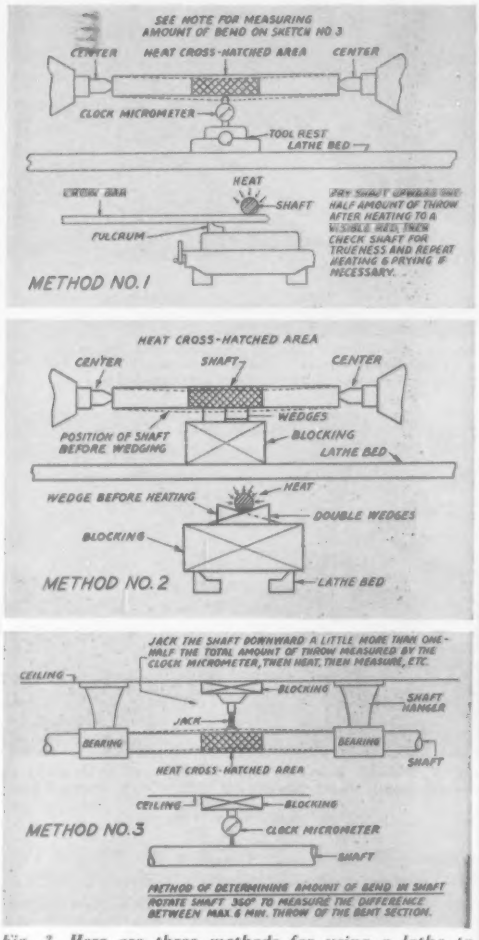


Fig. 3 Here are three methods for using a lathe to straighten bent shafts

If a single application does not correct the fault, repeat the entire procedure until the shaft is perfectly true.

By an alternate method, the warped area is determined in the same manner. After measuring the

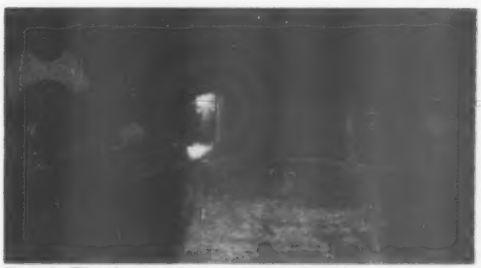


Fig. 4 The heavy plates of this dragline bucket were formed by heating with oxyacetylene flame

Fig. 6 Strap iron, heated by the oxyacetylene flame, was bent to form this attractive welded fence

Fig. 5 Two operators heated triangular patches in the side of a steel box that was warped. A 50-ton jack, pulled the sides in as the heat was applied

Fig. 7 An angle iron frame can easily be made by notching with the cutting blowpipe then heating, bending and welding to shape

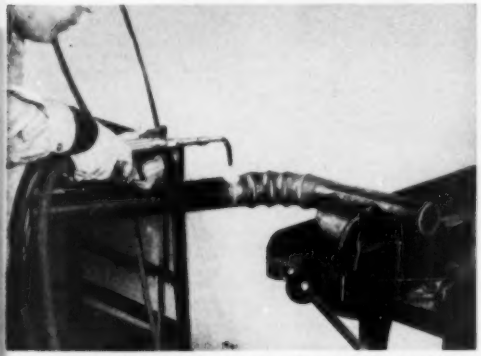


Fig. 8 Wrinkle-bends in pipe can be made by heating a narrow band about two-thirds of the way around and applying a bending force

Fig. 9 Heavy boiler plates are formed to exact shape by oxyacetylene heating

amount of bend, a pair of wedges (as shown in Fig. 3(B)) of the correct size are driven between the outside of the bend and the lathe bed. The shaft is then heated at the inside of the bend so that the stress set up by the driven wedge will force the shaft back into alignment. Repetition may be necessary to correct excessive warpage.

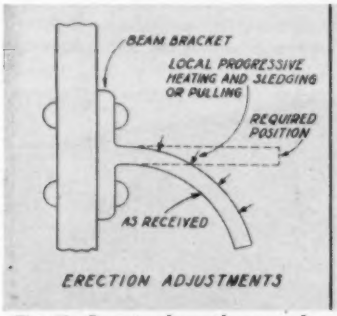


Fig. 10 Structural members can be adjusted during erection in the field by sledging or pulling after local heating with the oxyacetylene blowpipe

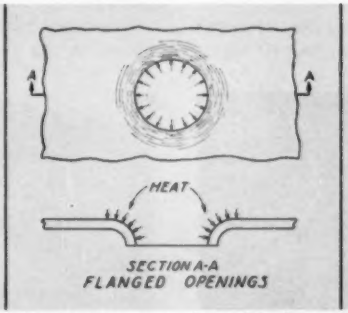


Fig. 11 Flanges are formed by heating the entire area and then forging to shape. Nipples in boiler plate can be made in this way

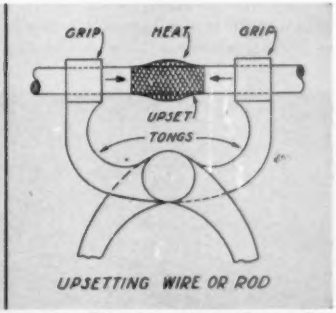


Fig. 12 Tie rods or wire spokes can be shortened slightly by heating a small section and applying force on each side to cause upsetting

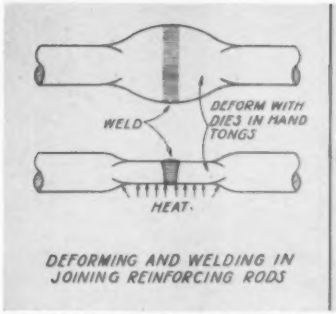


Fig. 13 Rods can be easily welded together if the ends are first heated and deformed as shown

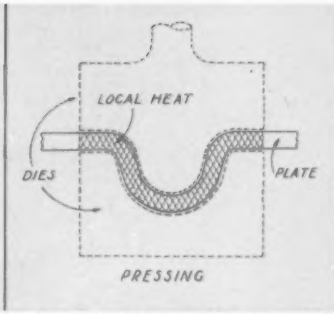


Fig. 14 Angle iron can be shaped as required by heating the angle iron and forcing it to the contour of a templet

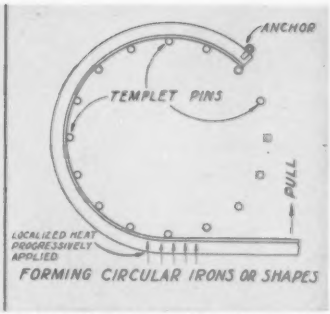


Fig. 15 For hot-forming, the area of a plate is heated and then formed to the desired shape in suitable dies

If the bent shaft is too long to be set up in a lathe it may be left in its hangers. After checking the hanger bearings to determine play or lost motion, firmness and rigidity, a measuring fixture is set up to measure the amount of bend (see Fig. 3(C)). The high spot is then heated with the blowpipe and forced into line by means of a jack.

The forming of heavy plates is another good example of the value of oxyacetylene heating. In the production of dragline buckets the plates are formed to the desired shape by this method. The tailor-made, $1^1/_2$ yard bucket shown in Fig. 4 is being formed from $1^1/_4$ in. plate.

SOME SHOP JOBS

Fast, efficient heating can be done by any shop by using the oxyacetylene heating blowpipe. In ornamental iron work, for example, oxyacetylene heating can be used by skilled craftsmen to produce attractive fences and gates. Strap iron is used in their construction and is heated and usually bent to contour.

Such things as welding trays and welding tables can easily be made from a single piece of angle iron. Three 90-deg. notches are cut out of one leg at the point that will form three of the corners of the frame. Each end of the same leg is cut at 45 degrees. The uncut leg is then heated at each notch, bent to a right angle, and checked with the square. When the bends are completed the two ends will be in a position for welding. Many bent and twisted parts, such as binder wheels, can be heated and reshaped with a hammer.

AUTOMOTIVE REPAIRS

Bent automobile frames are easily straightened by quickly bringing the section with the greatest amount of bend to a bright red heat and then straightening with a hammer. This process is also used to straighten bodies and fenders, heat body sections to restore their shape by shrinkage, and heat bearings before rebabbitting.

PIPE WORK

Wrinkle-bending, a special method for bending both steel and non-ferrous pipe so as to produce exactly the change in direction desired, is shown in Fig. 8. In this process a narrow band about $^2/_3$ of the way around the pipe, perpendicular to the pipe center line, is heated to a bright red. One or more blowpipes are used, depending on the pipe size and the wall thickness. When a bending load is then applied in the proper direction, the heated metal will upset and wrinkle and upon cooling leave the pipe with a permanent change of direction.

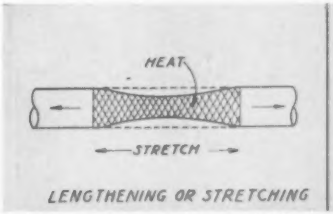


Fig. 16 Bars can be "necked-in" or stretched slightly by heating with the flame to a dark red and pulling the ends

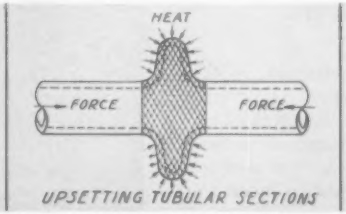


Fig. 17 Sections of tubing can be upset or the ends belled by heating a band entirely around the tube and exerting forces as shown

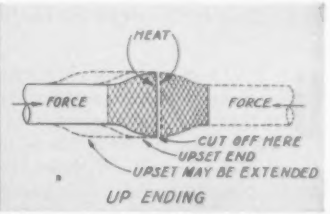


Fig. 18 Upsets can be formed on bars where desired, or bars can be upended where necessary by the application of heat and force

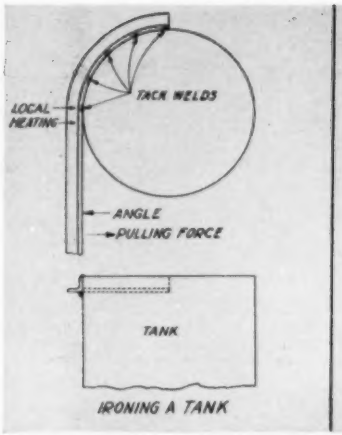


Fig. 19 In forming an angle iron brace for the top of a tank, the same blowpipe can be used for the heating as for the tack-welds

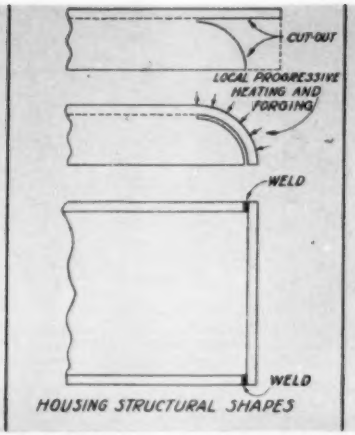


Fig. 20 Structural shapes can be made by cutting, bending, welding and heating with the blowpipe to form just the shape desired

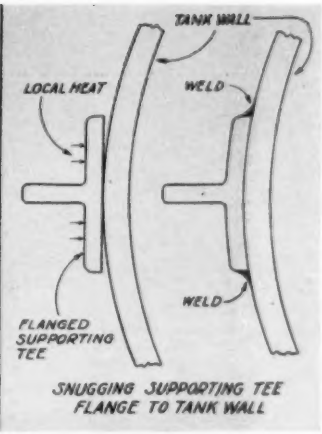


Fig. 21 Supporting tees can be formed to fit the outer tank wall and then welded into position with the same blowpipe

OTHER JOBS

Heat from the oxyacetylene flame is used in the boiler shops in turning up plate edges, bending boiler head flanges, and forming plates to be lap welded. Fitting flanges or heads to tanks that are slightly out of round, is made easy by heating them to formed sections and hammering to shape. Much time is saved during the fabrication of tanks by bending angle iron around them and tack-welding to assure neat, snug fits.

Circular forms of bars or structural shapes can be quickly and accurately made by continuous heating and bending. A multi-flame heating head is ideal because it quickly heats relatively large areas.

Oxy-acetylene heating is also a valuable tool in the shipbuilding industry. In making ship repairs, the flame is used to advantage in removing buckles from jammed, bent or distorted plates. It is also used for heating, bending, and straightening in the angle shop and in the flange shop.

Recording Voltmeter Checks Quality of Automatic Welds

by George A. Hatfield

ON SOME of the wash pipes manufactured by the National Supply Co., a machined steel ring is welded to the tubular body at one end to form a shoulder. The welding is done by the submerged-arc method on an automatic machine. Since the arc and bead are hidden from the operator during application, he cannot check the work or make adjustments for erratic behavior

George A. Hatfield is Production Superintendent with the National Supply Co., Torrance, Calif.

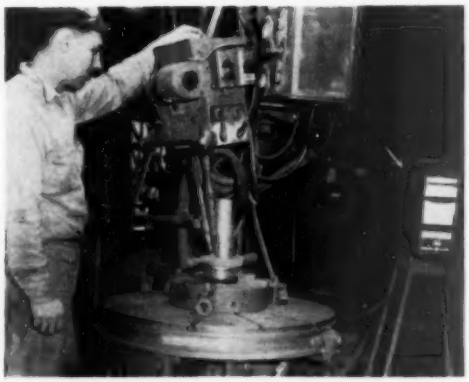


Fig. 1 Automatic welder equiped with a strip-chart voltmeter used to measure voltage variation across the arc

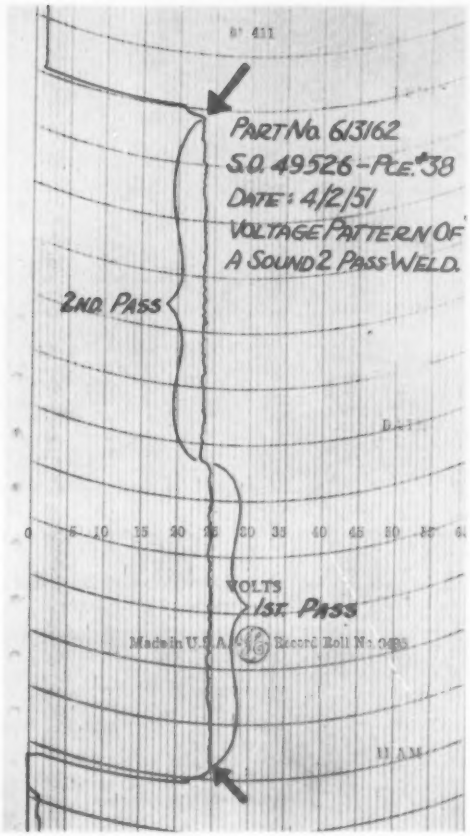


Fig. 2 Chart line within the two arrows shows the voltage pattern of the arc during a sound two-pass weld

while the weld is being made. To be on the safe side, the weld was being made in two passes, one over the other, to get a high-quality leakproof joint.

Even with this practice, the company had no definite assurance of a quality weld or evidence when the machine was operating erratically until the part was tested and inspected. What they wanted and needed was some means of indication that could be interpreted in terms of either harmful or merely incidental departures from normal.

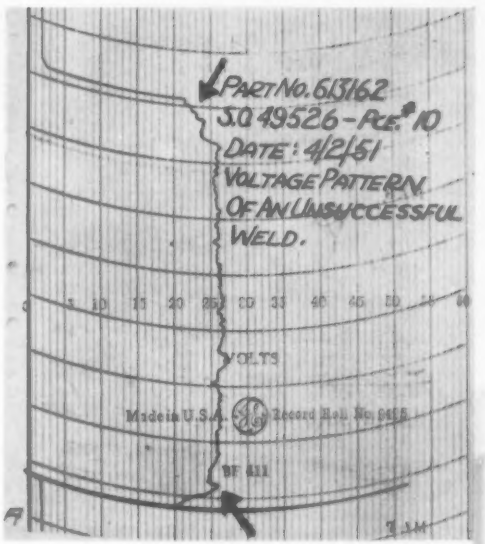


Fig. 3 Voltage pattern of an unsuccessful weld caused by lack of root penetration

After investigating several suggested methods, a joint committee from the weld shop and plant electrical department selected the idea of measuring the voltage variation across the arc as being the best telltale of conditions in the weld. Connected across the electrode and work, the strip-chart recording voltmeter selected has been successfully providing, according to the company, true pictures of the welds that match X-ray tests.

To correlate the pattern on the chart with the welded part, both the part and its chart pattern are numbered, and if the chart curve deviates from normal, the part is forwarded to the laboratory for X-ray. As a means of reducing X-ray examinations to those parts exhibiting flaws that might cause leakage, they are now building up an album of records by attaching the voltmeter chart to its corresponding X-ray film together with a statement of facts bearing on the case.

As the album library grows, the information collected will be used to identify variations on the voltmeter chart with the type of operating incident and effect on the product to minimize the number of X-rays needed.

the AMERICAN WELDING SOCIETY

activities • related events

Power Supply for Resistance Welding Machines

A pamphlet, WELDING JOURNAL size, of 59 pages has been prepared bythe AIEE Subcommittee on Power Supply for Resistance Welding Machines. Recognizing that the installation and use of any resistance-welding process vitally concerns not only the industrialist requiring the process but also the welding machine manufacturer and the utility supplying the electric power as well, the committee has in this report brought together much pertinent data from the knowledge, literature and experience in all these fields.

This publication supersedes the AIEE reports of the same title presented in 1940–1. The new work is required by developments in welding machines, new processes, better analysis of certain phenomena (such as measurement of instantaneous loads, and interference between welders) and a clearer understanding of the whole problem of power supply for resistance welders.

This report is not intended to be a complete solution of all welding problems, but should direct attention to the special electrical features involved so that a full analysis developed for a welding project can be readily understood and utilized by manager, master mechanic and electrical engineer.

Arrangements have been made for distribution of this report to members of the AMERICAN WELDING SOCIETY at the regular price of one dollar. Orders should be addressed to F. J. Mooney, Assistant Secretary, AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

Test Laboratory Plays Host to Ship Structure Group

By W. H. Wooding, Industrial Test Laboratory

On Friday, Apr. 25, 1952, the Industrial Test Laboratory was host to the Explosion Test Advisory Committee, a subcommittee of the Ship Structure Committee. This meeting, convened by the Chairman, Lt. Comdr. P. Hinkamp, USN, was for the purpose of formulating a test program for the continuation of the project during the coming year.

It is the responsibility of the Ship Structure Committee "to prosecute a research program to improve the hull structure of ships by an extension of knowledge pertaining to the design, materials and methods of fabrication." This committee was instituted by the Secretary of the Treasury during 1946.

At present, the committee is made up of the Engineer-in-Chief of the U. S. Coast Guard, as chairman, and the member agencies, the U. S. Maritime Administration, The American Bureau of Shipping, the Military Sea Transport Service, USN, and the Bureau of Ships, Department of the Navy.

The subcommittee which plans the technical phases of the work is composed of two representatives from each of the member agencies, together with liaison representatives from the American Iron and Steel Institute, the Welding Research Council, the Society of Naval Architects and Marine Engineers and the British Joint Services Mission.

The Explosion Test Project is one of 18 projects comprising the current research program of the Ship Structure Committee. This project is primarily concerned with the evaluation of various types of steel and fabrication techniques proposed or used in ship construction. The test determines the relative toughness of the steel or welded structure by subjecting test panels to the effects of direct explosion and establishing the conditions which cause rupture.

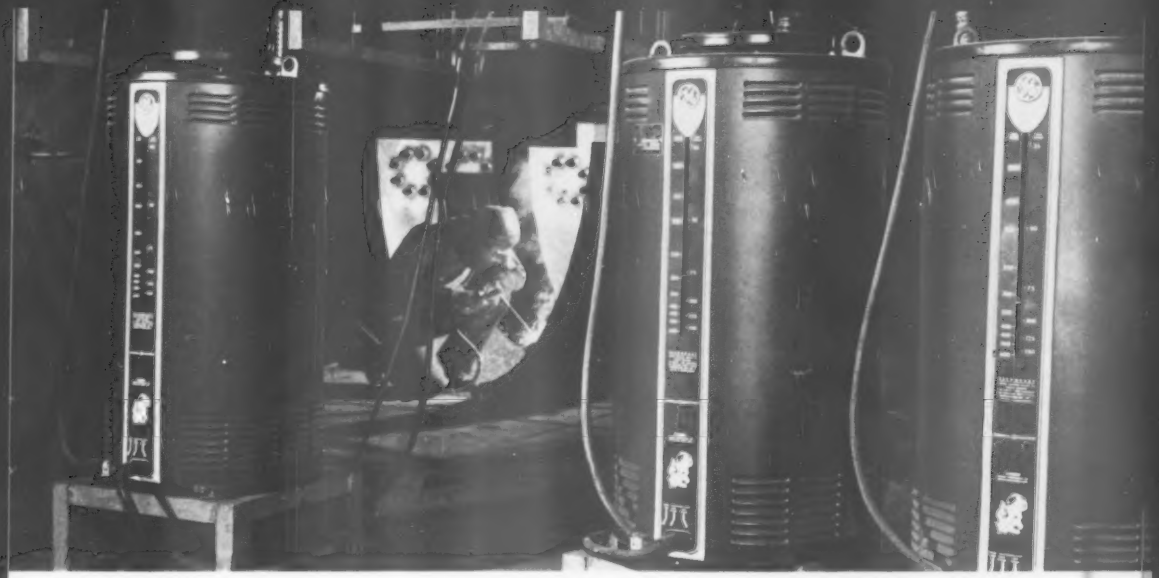
The Industrial Test Laboratory has a very active part in this project and has fabricated test panels using newly developed high-yield notch-tough steels and low-hydrogen, mineral-covered welding electrodes.

Frankford Arsenal Host to Brazing Committee

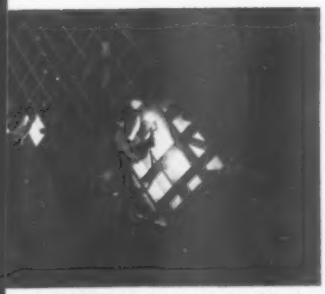
Frankford Arsenal in Philadelphia, Pa., played host to the AWS Committee on Brazing and Soldering on May 7th and 8th. The Committee took time out from its two-day meeting at the Arsenal to inspect some of the brazing, welding and related operations.

After an address of welcome by Col. D. J. Murphy in charge of the Pittman-Dunn Laboratory, speaking in behalf of Col. Ward E. Becker, Commanding Officer, the Committee was divided into several small groups. Each group was taken on a carefully arranged tour of welding, brazing, casting, heat treating and other metal-working developments and operations. Guides from the Laboratory's staff answered the many questions of the Committee's members.

Members of the committee include: (Back row, *left to right*) W. H. Wooding, Test Laboratory; Comdr. J. F. Starks, R.N.; F. C. Bailey, National Research Council, Washington; J. Hill, Design; E. Foehl, Design, and C. T. Gayley, Test Laboratory. (Front row, *left to right*) G. Mikhalapov, Metallurgical Research and Development Commission, Washington; A. S. Marthens, Bureau of Shipping; W. Spraragen, Director, Welding Research Council, New York; Lt. Comdr. P. Hinkamp, Bureau of Shipping; E. M. MacCutcheon, Bureau of Shipping; Capt. R. H. Lambert, Shop Superintendent, and W. S. Pellini, Naval Research Laboratory, Anacostia, D. C.

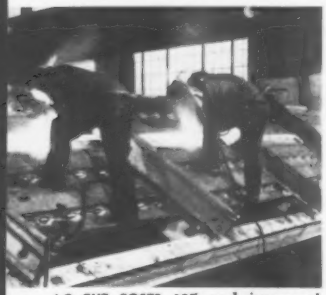


BEST FOR 3 OUT OF 4 WELDING JOBS!

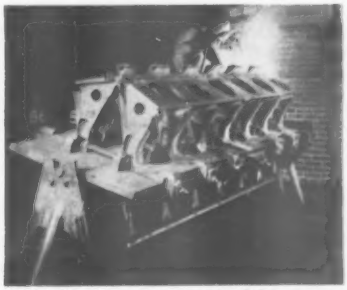


WELDING SPEEDS INCREASED 20% after this company switched to AC. Deposition rates may be doubled because AC permits the use of higher currents and larger electrodes.

AC ELIMINATES TROUBLESOME ARC BLOW, permitting these weldors to deposit $\frac{3}{8}$ inch fillet up to 20% faster. AC is the ideal choice for deep fillet welding because the operator can easily control the arc.



AC CUT COSTS 10% and increased welding speeds 15% for this iron works. With AC, you save four ways —on labor, electrodes, power and original cost.



IMPROVED WELD QUALITY enabled this plant to meet rigid specifications on diesel engine crank cases and marine gear cases. The absence of arc blow makes it easy to deposit weld metal smoothly and uniformly, even in grooves and corners.

G-E AC Welders Increase Speed, Improve Weld Quality, Cut Costs, Eliminate Arc Blow

See Your G-E Arc Welding Distributor for complete information on G-E AC welders. They are available in 200- to 500-amp ratings for indoor or outdoor use. Most models are available on short delivery. Your distributor also carries a complete line of DC, engine-driven, Inert-Arc and Atomic-Hydrogen welders, plus electrodes and accessories. You can find your nearest distributor's name by looking for General Electric under "Welding Equipment" in the yellow pages of your telephone directory.

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Please send me immediately publications on the following G- AC welders.

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- ☐ 200-amp, GEC-553
- ☐ 300-amp, GEC-652
- ☐ 400-amp, GEC-750
- ☐ 500-amp, GEC-812
- ☐ 300-amp Indoor or Outdoor Model, GEC-779

Name .....

Company .....

Address .....

City ..... State .....

The Committee, shown in front of the Pittman-Dunn Laboratory, also made progress in preparation of the Brazing and Soldering Manual, its current project.

Centennial

The 100th anniversary of the separation of civilian engineering from military engineering in this country is the occasion for celebrating a century of engineered progress in 1952. The celebration will reach its climax in September, with a great convocation in Chicago.

The American Society of Civil Engineers, which came into being in 1852, as the first national engineering society in the United States, set its sights on its centennial year in the hope of making its 100th anniversary an occasion in which all branches of engineering would join. This ambition is being realized, so that the Centennial of Engineering betokens the accomplishments and future of every branch of engineering rather than being commemorative of the single society that was founded 100 years ago.

Backbone of the convocation is found in events arranged by the corporation, Centennial of Engineering, 1952. These special events are not a responsibility of any of the participating societies. The program will give to engineering and to the general public a remarkable series of 12 symposia on major subjects. These sessions are distributed throughout the convocation period, September 3rd to 13th. Each will be conducted by an eminent chairman and the main speakers will be distinguished experts in their respective fields. Papers will be presented in language understandable to the layman. In short, these symposia will be of large popular interest and accomplish a great deal in realizing the purpose of bringing about a better public understanding of engineering and of the reasons why America has become so great.

Also included are a reception for foreign delegates on September 3rd and significant ceromonies on September 10th which is designated as Centennial Day. The latter will include a special luncheon and an all-inclusive evening party.

That an extraordinary interest is being taken in the Convocation by the entire profession of engineering is evident from the fact that 51 engineering organizations have scheduled meetings in addition to the symposium programs during the September period. Thirty-nine of them will hold technical sessions, and, in a number of instances two or more organizations will collaborate in joint sessions. The attendance is expected to reach 25,000.

Obviously, a tremendous amount of work is necessary to develop and coordinate the many hundreds of technical sessions and other functions involved in the meetings of so many societies during the 11 day period. Each society has full responsibility for arranging its own meeting, subject general coordination under the over-all supervision of a Convocation Committee of the Board of Directors of the Corporation. This great task rests in the hands of two committees composed of representatives from each of the participating societies. One is the Coordinating Committee on Technical Programs under the chairmanship of G. Donald Kennedy, Assistant to the President of the Portland Cement Assn. The second is a correspond-

INDEX TO ADVERTISERS

Air Reduction ..... Outside back cover
The American Brass Co. 625
American Chain and Cable Co. 626
American Manganese Steel Division 615
Ampco Metal, Inc. 617

Becker Brothers Carbon Co. 628

The Champion Rivet Co. 612
Chicago Boiler Company 614
Clark Equipment Company 631
Crucible Steel Company of America 611

Eutectic Welding Alloys Corp. 607

General Electric 603

Hobart Brothers Company 543

The International Nickel Company, Inc. 613

Jackson Products ..... Inside back cover

The Lincoln Electric Company 627
Linde Air Products Company, a Division of Union Carbide and Carbon Corporation 546

P. R. Mallory & Co., Inc. 545

Metal & Thermit Corporation 544

National Carbide Company 618
North American Aviation, Inc. 631

Page Steel and Wire Division 626
Pennsylvania Optical Company 633

Square D Company 621
Stulz-Sickles Co. 605

Tempil® Corporation 605
Turco Products, Inc. 608, 609
Tweco Products Company ..... Inside front cover

Union Carbide and Carbon Corporation
Linde Air Products Company 546
United States Testing Company, Inc. 631

Victor Equipment Company 548

Wagner Manufacturing Co. 634
Welding Fittings Corp. 619
Weldwire Company, Inc. 622
Westinghouse Electric Corporation 628
J. H. Williams & Co. 632
Worthington Corporation 623

ing Committee on General Arrangements under the Chairmanship of Howard F. Peckworth, Managing Director of the American Concrete Pipe Assn. The two committees meet jointly every month and all plans are progressing very satisfactorily.

The 39 units of engineering which are planning technical sessions are:

American Assn. of Engineers, American Chemical Society (Chicago Section), American Concrete Institute, American Geophysical Union, American Institute of Architects, American Institute of Chemical Engineers, American Institute of Electrical Engineers, American Institute of Mining and Metallurgical Engineers, American Iron and Steel Institute, American Meteorological Society, American Public Health Assn. (Engineering Section), American Railway Engineering Assn., Assn. for the Advancement of Science, American Society of Agricultural Engineers, American Society of Civil Engineers, American Society for Engineering Education, American Society of Lubrication Engineers, American Society of Mechanical Engineers, American Society of Refrigerating Engineers and the American Society of Safety Engineers (Chicago Chapter).

Also, the American Society for Testing Materials, American Society of Tool Engineers, American Standards Assn., AMERICAN WELDING SOCIETY, Armour Research Council Association of Consulting Management Engineers, Chicago Technical Council, Illuminating Engineering Society, Industrial Management Society, Institute of Radio Engineers, Institute of Traffic Engineers, National Conference on Industrial Hydraulics, Society for Advancement of Management, Society of American Military Engineers, Society of Automotive Engineers, Society of Naval Architects and Marine Engineers, Society of Women Engineers, United States Navy (Bureau of Yards and Docks) and the Western Society of Engineers.

Among the joint sessions will be two all-day programs of the American Concrete Institute and the ASCE. The American Geophysical Union and the American Meteorological Society will combine their entire activities into one program. The American Institute of Architects and the American Standards Assn. will have a session together. So too will the American Institute of Electrical Engineers and the AMERICAN WELDING SOCIETY.

The American Rocket Society will have a session with the ASCE Engineering Mechanics Division and ASME. The American Public Health Assn. and the ASCE Sanitary Engineering Division will hold a joint meeting. There will be a joint session of the American Railway Engineering Assn. and the ASCE Structural Division, ASME, ASTM Committee D-7. A paper will be discussed by the American Society for Engineering Education and the Engineer's Council for Professional Development.

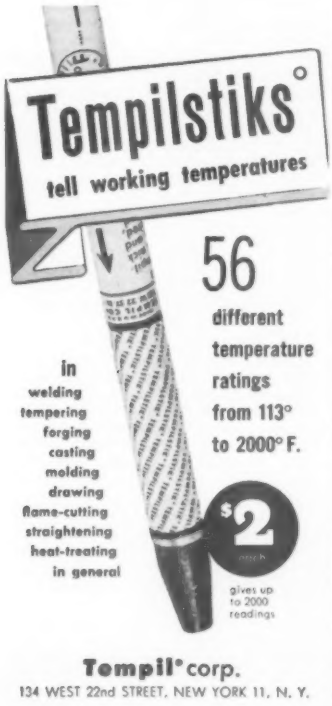
The American Society of Mechanical Engineers will meet with the ASCE Engineering Mechanics Division in a joint session and will hold one session with the ASCE Structural Division. It also will have a paper under discussion with the American Rocket Society.

Exceptional opportunities for sightseeing and entertainment are provided by Chicago and numerous tours are being arranged. These will be indicated in the Official Centennial Program. This program, which will be very detailed, and which is intended to be a clear, simple and helpful guide, is in preparation now by the staff of the Centennial Corporation.

Employment Service Bulletin

Services Available

V-273. High-type manufacturer's agent calling on welding distributors midwest, mid-south to sell highly accepted apparatus and supplies—established accounts most areas.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NEWS OF THE INDUSTRY

Industrial Specialist Examination Announced

The United States Civil Service Commission announces an Industrial Specialist examination for filling positions with the U. S. Navy Shipbuilding Scheduling Activity in Philadelphia, Pa. The positions of Commodity Industry Specialist and Shipbuilding Material Scheduling Specialist will also be filled from the lists established from this examination. The positions pay $5060 to $9600 a year.

To qualify, applicants must have had from 5 to 6 years of appropriate experience or a combination of education and experience.

Applications must be filed with the Recorder, Board of U. S. Civil Service Examiners, Philadelphia Naval Shipyard, Naval Base, Philadelphia 12, Pa.

New Scientist Examination Announced

The Civil Service Commission is anxious to bring its new scientist examination announcement to the attention of qualified persons. Chemist, physicist, metallurgist, mathematician and electronic scientist positions in various Federal agencies in Washington, D.C., and vicinity will be filled from this examination. The salaries range from $3410 to $10,800 a year.

To qualify, applicants must have had appropriate education or experience or both. In addition, for jobs paying $4205 and above, they must have had professional experience in the field for which they apply. No written test is required. Applications will be accepted from senior or graduate students who expect to complete all the scholastic requirements for the positions within 6 months.

Applications will be accepted by the Board of U. S. Civil Service Examiners, National Bureau of Standards, Washington 25, D. C., until further notice.

Welding Bottlenecks in Dutch Defense Industries Bring Study Team to U. S.

Welding problems which have caused bottlenecks in shipbuilding and other defense industries in The Netherlands have brought ten Dutch technologists to the United States in search of better production techniques. The team arrived in New York City on May 5th for a 5-week plant tour sponsored by the Mutual Security Agency under its productivity and technical assistance program.

Dutch industries employ some 15,000 welders who are encountering technological problems in welding methods, materials and equipment that result in slow downs, bottlenecks, loss of money, waste of man-hours and materials throughout the metal-working industry. The team currently in the United States consists of specialists in those fields where welding problems are most urgent, such as shipbuilding, large steel construction, chemical, fuel and electrical industries.

In 1950, The Netherlands sent another welding team to the United States, and this team made recommendations which Dutch workers have applied to the welding of various metals. The second team is studying weldability of carbon steel, problems of welding alloy steels and face hardening, welding of nonferrous metals, corrosion problems in welded constructions, and electro-physics of the welding arc.

National Power Show to Be Held in New York December 1st to 6th

Announcement is made that the Twentieth National Exposition of Power and Mechanical Engineering will be held in Grand Central Palace, New York, December 1st to 6th, next. It will be held again under the auspices of the American Society of Mechanical Engineers, whose annual meeting will be in session during the same week, thus assuring a large attendance of professional men.

As heretofore, the biennial event will include exhibits representing every kind of equipment used in the generation and distribution of power, with specific applications in many new and more efficient ways. There will be upwards of 300 different kinds of products on display, occupying three entire floors of the Palace.

New Steel Castings Specification Chart

Standard specifications for more than 70 designated classes of steel castings are incorporated in a comprehensive new summary chart compiled by the Steel Founders' Society of America.

Intended to serve as a reference aid to design engineers and purchasing department engineering staffs, the newly prepared chart covers pertinent data on virtually all general engineering types of steel castings, together with recently adopted specifications and some revisions of previous specification standards.

Essential information included in the simplified tabular listings includes types of heat treatment, chemical compositions and mechanical properties of varying specifications, with detailed ready-reference data on specific tensile strength, yield point, elongation, reduction of area, bend, impact hardness and other indicated test procedures.

Special attention is devoted to some miscellaneous requirements of radiographic, magnetic particle, hydrostatic, and destructive testing, and welding, where indicated.

Copies may be obtained from F. Kermit Donaldson, executive vice-president, Steel Founders' Society of America, 920 Midland Building, Cleveland 15, Ohio.

Banner NWSA Annual Meeting

The National Welding Supply Assn. held a very successful Eighth Annual Convention on May 5th, 6th and 7th at the Hotel LaSalle, Chicago, Ill., and elected its new officers for the 1952–53 year, in the order following:

G. Milton Sims, AWS, President, Absco Welding Supplies, Los Angeles, Calif.; Carl W. Bernes, Vice-President—Eastern Zone, Welders Supply Co., Philadelphia, Pa.; W. A. Rice, AWS, Vice-President—Southeastern Zone, Virginia Welding Supply Co., Charleston, W. Va.; A. L. Hill, AWS, Vice-President—Southwestern Zone, Hill Welding Supplies, Dallas, Tex.; James N. Alcock, AWS, Vice-President—Central Zone, Saginaw Welding Supplies, Saginaw, Mich.; R. T. Rogers, AWS, Vice-President—West Central Zone, R. & R. Welding Supplies, Des Moines, Iowa; Elmer Bakke, AWS, Vice-President—Western Zone, Welders Supply Co., Seattle, Wash. Directors—Full Term: W. I. Hughes, Hughes Oxygen Co., Shreveport, La.; E. C. Caluwaert, AWS, Okeh Welding Supply, Cincinnati, Ohio; A. G. Pond, A. G. Pond Co., San Jose, Calif.; J. L. Kirk, Jr., Basholor-Sowers Welding Services, Inc., Bluefield, W. Va. M. J. Lampton, AWS, Director—Expiring 1954, Lampton Welding Supply, Wichita, Kan.; Nolen E. Elam, AWS, Director—Expiring 1953, Industrial Welding Supply, Houston, Tex.

NWSA has had a remarkably successful membership year having, during the past year, increased its welding supply dealer membership from 211 to 314. The outgoing President, R. S. McCracken, Jr., AWS, R. S. McCracken & Sons, Inc., Philadelphia, was widely congratulated upon his energy and activity during his term of office and commended for his membership zeal.

During the three-day activity, all phases of the dealers' and distributors' problems were discussed under the direction of capable industry readers. The novel "Contact Booth" program, instituted several years past, reached a peak in activity this year with 61 welding supply and equipment manufacturers participating. Congratulations are extended to the NWSA and to their Secretaries, Fernley and Fernley, of Philadelphia.

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"The folding press shown in the photos had been in service a great many years and during that time, cracked one leg of the side frame. Temporary repairs were unsuccessful and cracking of two other legs occurred, making the machine unusable.

After various welding companies had decided against repairing this machine by any welding method, we called for a EUTECTIC Consultation and were told that the repair could be made with EutecTrode 24, your special electrode for welding cast iron "cold".

As recommended, we supported the weld repair by boxing in the complete side frame with steel plate and attaching the closely fitted plate to the frame with fitted bolts. The repair made in this manner was completely successful and the machine now operates as efficiently as a new unit.

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Babcock & Wilcox Move to New Headquarters

The Babcock & Wilcox Co., nation's largest producer of steam generators and related equipment, opened offices in May at new headquarters in the recently completed 32-story fully air-conditioned Chrysler Building East at 161 E. 42nd St., following one of the largest moves from the financial district in many years. It required 220 truck loads to transfer the company's thousands of desks, files, office machines and library records from the old headquarters at 85 Liberty St. The company has had its general office in the downtown district of New York for more than three quarters of a century.

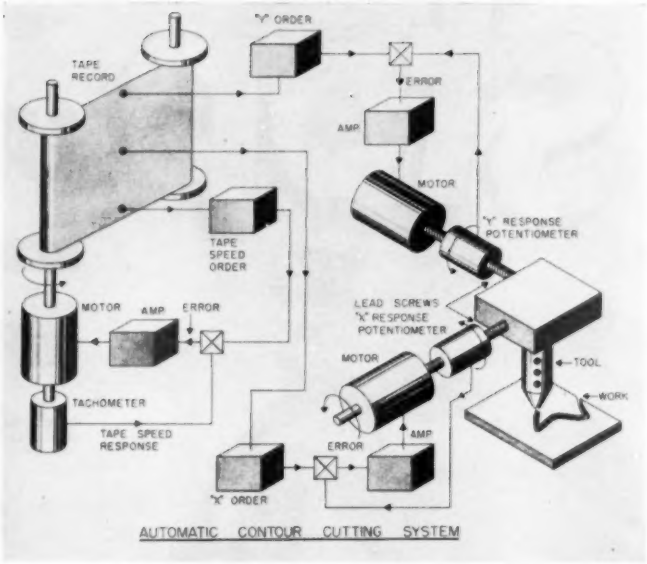
The company has a research center and eight manufacturing plants in Ohio, western Pennsylvania, Georgia, Mississippi, North Carolina and Texas. It employs approximately 14,000 people, of which 825 are in the New York office. Its products are separated into five general groups—stationary boilers, marine boilers, tubes, refractories and special products.

Sales offices of The Babcock & Wilcox Co.'s Tubular Products Division were not affected by the move, remaining in their present location at 22 E. 40th St.

In its new headquarters The Babcock & Wilcox Co. occupies the second through the sixth floors, totalling approximately 120,000 sq ft of space. The company is the largest single tenant in Chrysler Building East which was constructed by the Turner Construction Co.

Automatic Control Highlight Meeting of ASTE

The May 1952 (final Spring) Meeting of the Greater New York Chapter 34, American Society of Tool Engineers, held May 12th at the Hotel New Yorker, had as its topic, Automation of Machines and Processes. The Newer Techniques of Automatic Control. The occasion commemorated the growing interest in making machines and processes automatic, which has spread widely from the "push-button" lathe first demonstrated by Arma Corp. in 1949.



AUTOMATIC CONTOUR CUTTING SYSTEM

The technical papers that were presented covered the fundamentals and recent advances in the servomechanism and the steps now being taken to bring the "hardware" of automatic controls within the reach of a larger segment of American industry. Speakers were Julius Y. Kaplan and Lee Fraser, respectively, Head of Servo Section and Production Manager of Arma Corp., Brooklyn and Mineola, N. Y., subsidiary of American Bosch Corp.

Mr. Kaplan stated:

"Another machine control application for the servomechanism would be in automatic contour cutting. (See Fig.)

"In this system it is desired to cut contours of any shape without a master and without any pantograph-type linkage system.

"The principle used here is automatic plotting in rectangular coordinates.

"The drive uses a rectangular coordinate (X, Y) system. The separately driven 'X' and 'Y' lead screws position a single chuck in which is mounted a suitable cutting tool or possibly a flame cutter. The work is mounted on a stationary table. A response potentiometer furnishes a voltage which is an exact measure of the drive position with respect to a baseline. If this voltage is bucked against a calibrated order voltage in the null circuit of the servo, the drive will automatically position itself precisely to the ordered position.

"The order may be derived from some device like a 'piano-roll' type punched tape or a magnetic tape. On this tape are recorded in two rows the simultaneous 'X' and 'Y' coordinates of the desired contour as read off blueprint. These quantities produce accurate voltages on a digital

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THE DYE PENETRANT METHODS
IT'S NEW! CHEK-SPEK
HERE'S TURCO'S NEW PRODUCTION-LINE METHOD OF FLAW LOCATION...SIMPLE, SAFE & ACCURATE. SAVES YOU MONEY & TIME!
DEVELOPED FROM TURCO'S FLEXIBLE DY-CHEK PROCESS. ACCEPTED BY THE AIR FORCE...
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LASTING VISIBILITY OF FLAW INDICATIONS PERMITS ECONOMICAL RE-WORKING AT YOUR CONVENIENCE.
RE-WORK WELDERS SAY
MAKES EACH JOB EASIER BECAUSE WE CAN SEE WHERE THE DEFECTS ARE!

basis which order the respective drives to the proper point on the contour. A system like this lends itself very naturally to scale change merely by scaling the voltage excitation of the response potentiometer.

"Cutting speed depends on the speed of the tape drive. Variable speed control of cutting is possible by recording on a third row of the tape the instantaneous speed required. This order is transmitted to a lightweight tape drive servo. This feature might be very useful, particularly in cutting a casting of variable cross section."

Railroad Bridge Will Use Welded I-Beams

Twenty-seven huge I-beams, weighing almost 9 tons each, will help carry railroad traffic over the new Pennsylvania Railroad Mulberry St. Bridge in Baltimore. The special beams, over 62-ft long, are being fabricated by Maryland Drydock Co. in Baltimore.

Unionmelt welding is used to make strong welds among the three steel sections that make up an I-beam. After the sections are positioned on a special jig, tack welds are made to hold the parts together. Then a Unionmelt machine, mounted on a portable carriage which runs on tracks alongside the setup, makes the required welds between the parts.

Four fillet welds are made to join the parts. Direct current is used, about 750 amp.

Water Locks

Recent examples of skilled welding in Barukuk, Indonesia, are two huge water locks, built by Machinefabriek Braat, N. V., the largest construction company in the country, for installation in a dam in Barukuk.

Indonesian workmen used more than 2000 lb of General Electric W-25 (AWS-E6013) welding electrodes in assembling the 110,230-lb monsters. The welded seams are visible at right in the accompanying picture of one of the locks shortly before completion.

The dam, for which the locks were built, stores water for the irrigation of rice fields in this small village near Tjikampek, about two hours by car from Djakarta, Indonesia's capital.

Large tanks fabricated by Heliarc welding in Holland

Dutch Tanks Fabricated by Heliarc Welding

Aluminum storage tanks, almost 28 ft in diameter, and 33 ft high are fabricated by Heliarc welding in Holland. About 450 ft of welding is done on each tank to join the $^1/_2$-in. thick aluminum plates. The tanks will hold over 1,000,000 gal. of liquid, and are so large that they have to be transported by barges. These tanks are being fabricated by Nederlandse Koper Metaal Industrie at Delft, Holland.

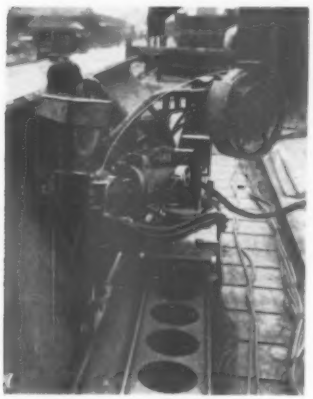

Fig. 1 Here is the setup for welding the beams. A Unionmelt machine is making a fillet weld at about 6 in per minute

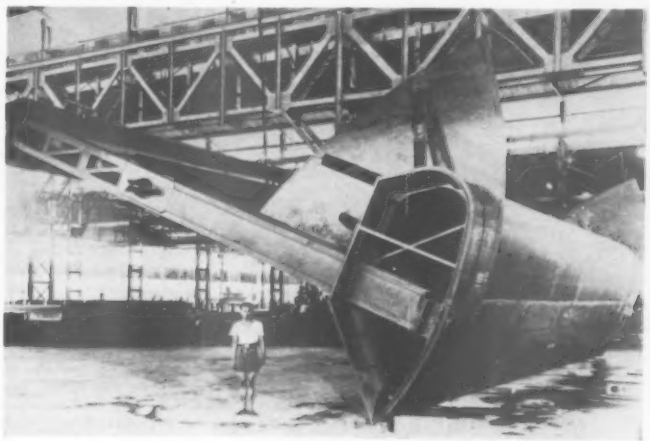

Photo courtesy General Electric Co.

CHIEF INSPECTORS REPORT
KEEPS ACCEPTABLE PARTS MOVING...ONLY SUSPECTED PARTS GO TO TRAINED INSPECTORS. SIMPLIFIES EVALUATION, CUTS DEPARTMENT COSTS.
PRODUCTION SUPTS. SAY
ELIMINATES INSPECTION BOTTLENECKS. PERMITS ONE MAN TO CHECK AS MANY PARTS PER HOUR AS HE CAN PICK UP AND PUT DOWN!
PLANT MANAGERS REPORT
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Gentlemen:
Please send me your latest information on the world's fastest flaw location methods—flexible ☐ Dy-Chek, or the production-line tool ☐ Chek-Spek, (check one or both). No obligation, of course.
NAME _____
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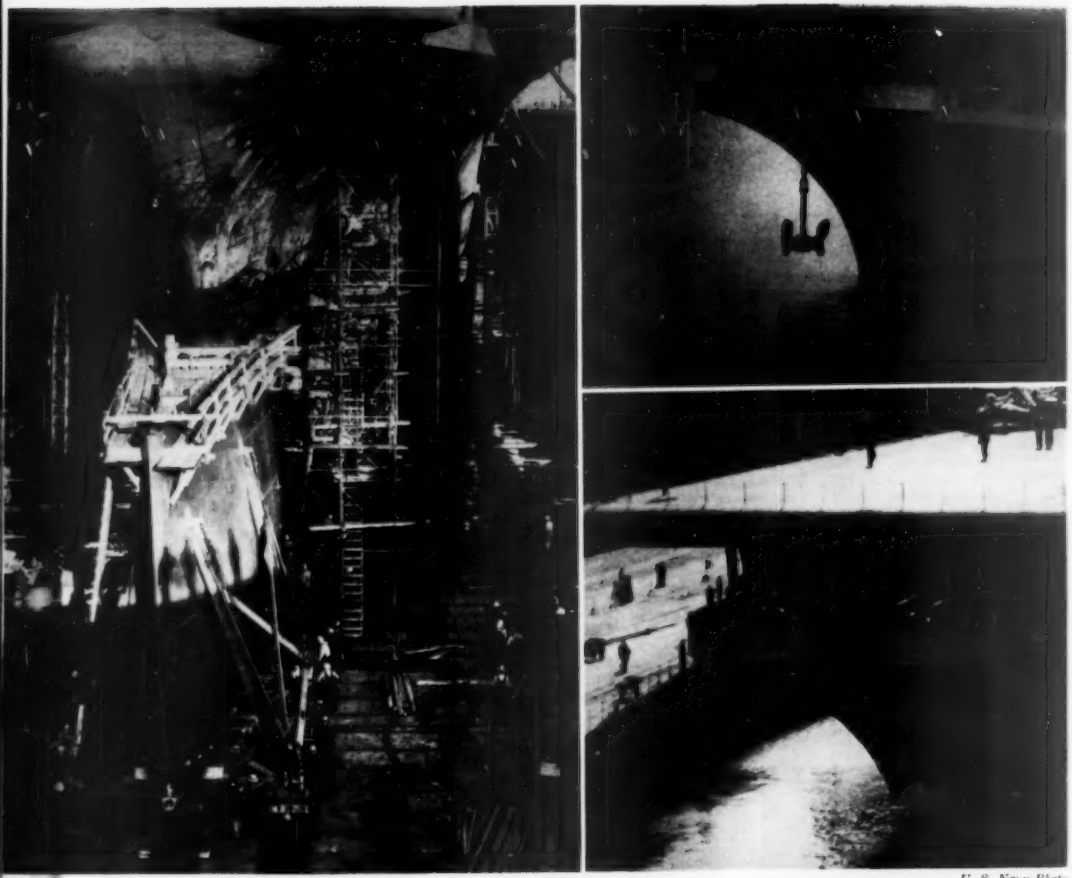
Simply staple coupon to company letterhead



U. S. Navy Photo

Welded Construction Holds *Wasp* Damage to Minimum Permits Speedy Repair

(Courtesy Metal & Thermit Corp.)

Accounts of the repair of the U. S. Navy's aircraft carrier *Wasp* have related the magnificent job done by repair crews in restoring a vital unit of America's defense system to duty in a record 10 days. This was not an accidental accomplishment. Behind the huge task lay hours and days of thinking and careful planning—planning which was under way almost as soon as it was learned there had been serious damage. Experts who were familiar with the *Wasp's* original construction were rushed out to meet the carrier in mid-Atlantic. These specialists began radioing instructions to repair crews at the Brooklyn and Bayonne Navy Yards in order that all would be in readiness upon the *Wasp's* arrival.

However, credit must also be given to the original designers and builders of the carrier who planned for welded construction. Only welded construction could have withstood the great impact of the collision between the *Wasp* and the destroyer *Hobson*. Also, the welded construction allowed the bow portion, which jutted out over the damaged section, to retain its alignment and withstand the heavy seas during the trip back to the United States.

The *Hornet*, a carrier of similar design under conversion, furnished the bow section necessary to return the *Wasp* to duty. This unit was cut away from the *Hornet* and every available man and piece of equipment was put to the task of joining it to the *Wasp*—another job, which could only have been done by welding.

Farsighted planning by the Navy Department and to speed execution of well-organized repair plans proved to be economical as well as expeditious. Tying up of a ship's crew of approximately 700 men for months in port was avoided and a badly needed fighting unit was quickly restored to duty.

Welded Pulley

One month was the time between receipt of order and delivery of this 2925-lb all-welded pulley, made by Link-Belt of San Francisco. Designed to transmit 75 hp at 150 rpm, the pulley is 83 in. in diameter. Customer specified cast steel but changed to welding when expense and delay involved in making a pattern was taken into consideration. The rim was rolled from plate $1^1/_4$ in. thick by $17^1/_2$ in. wide by 22 ft.

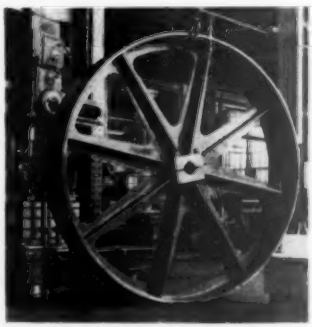


Photo courtesy Lincoln Electric Co.

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IT'S BETTER THESE WAYS:

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1. Rexweld builds up and holds on an edge better! This means less welding time is required.

INCREASE PRODUCTION

2. Rexweld flows more readily on flat surfaces! In machine gas welding operations valve companies have reported an increase in production per shift using Rexweld.

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4. Tests show Rexweld has better wearing qualities.

Hundreds of satisfied users, manufacturing such products as valves, oil pump parts, mixer shafts attest to Rexweld's ability to do a better job . . . at less cost! Rexweld is available in a wide range of grades to meet all requirements. Then too, Rexweld meets Government specifications. If you use hard surfacing rod, be sure you check Rexweld . . . it'll save you time and money.

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All-Welded Steel Bucket

Beads for a Better Bite

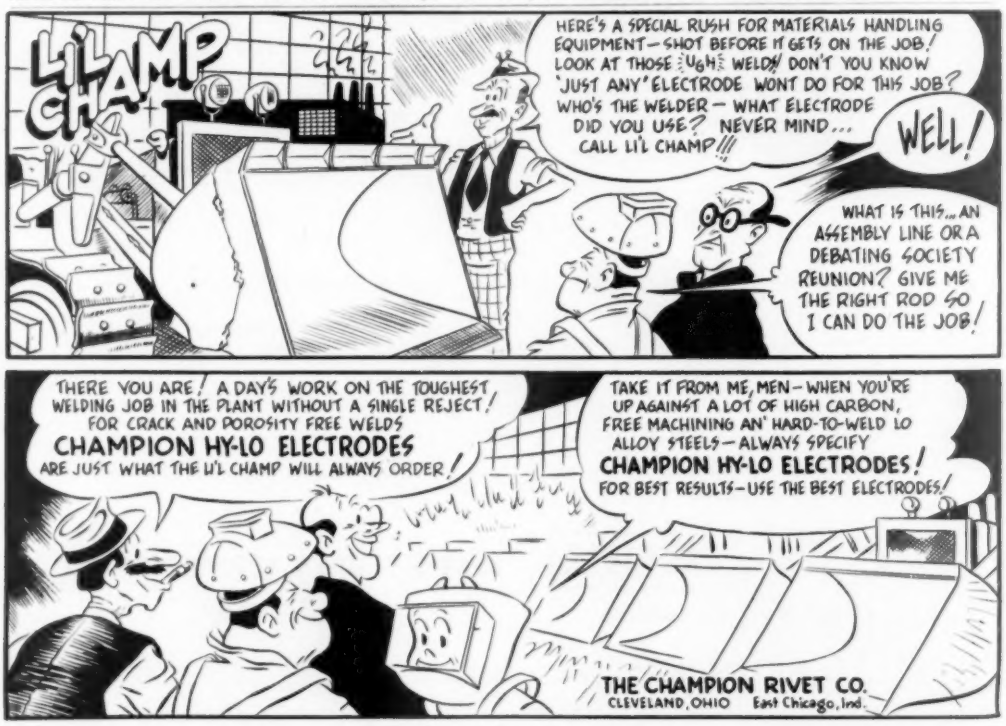
Thirty-five cubic yards is just a mouthful for this Marion all-welded steel bucket used in strip mining operations by the Sinclair Coal Co. Lip and teeth are of cast manganese steel, riveted to the fabricated body. As further protection against the scouring action of rock, earth and coal, the underside of the lip is reinforced with a series of 16 parallel beads of Faceweld No. 12, a coated tubular arc-welding electrode high in carbides of tungsten, chromium, vanadium and molybdenum. It is furnished by Lincoln Electric Co., Cleveland. This is believed to be a relatively new and economical method of hard-surfacing bucket lips. Operators claim the spaces between the beads fill up with excavated material, resulting in equivalent wear to that of a fully coated surface. The beads are $2^1/_2$ in. apart, extend across the bottom of the lip and a third of the way up the sides, as shown in the inset.

European Engineers to Study American Production Methods

Decision of the Mutual Security Agency at Washington to utilize the importance of the Centennial of Engineering, scheduled in Chicago this summer, to bring 200 leading European engineers to the United States to study American production methods, is announced by the Centennial's president Lenox R. Lohr.

The foreign group is expected to arrive in the United States well in advance of the official opening of the big engineering society convocation part of the Centennial program on September 3. During the convocation, more than 50 leading American and foreign engineering societies will cooperate in a 10-day program of joint meetings covering all important aspects of engineering and the many fields it serves.

Present plans call for the foreign visitors


LIL CHAMP
HERE'S A SPECIAL RUSH FOR MATERIALS HANDLING EQUIPMENT—SHOT BEFORE IT GETS ON THE JOB! LOOK AT THOSE UGH! WELDS! DON'T YOU KNOW 'JUST ANY' ELECTRODE WONT DO FOR THIS JOB? WHO'S THE WELDER—WHAT ELECTRODE DID YOU USE? NEVER MIND... CALL LI'L CHAMP!!!
WELL!
WHAT IS THIS... AN ASSEMBLY LINE OR A DEBATING SOCIETY REUNION? GIVE ME THE RIGHT ROD SO I CAN DO THE JOB!
THERE YOU ARE! A DAY'S WORK ON THE TOUGHEST WELDING JOB IN THE PLANT WITHOUT A SINGLE REJECT! FOR CRACK AND POROSITY FREE WELDS CHAMPION HY-LO ELECTRODES ARE JUST WHAT THE LI'L CHAMP WILL ALWAYS ORDER!
TAKE IT FROM ME, MEN—WHEN YOU'RE UP AGAINST A LOT OF HIGH CARBON, FREE MACHINING AN' HARD-TO-WELD LO ALLOY STEELS—ALWAYS SPECIFY CHAMPION HY-LO ELECTRODES! FOR BEST RESULTS—USE THE BEST ELECTRODES!
THE CHAMPION RIVET CO.
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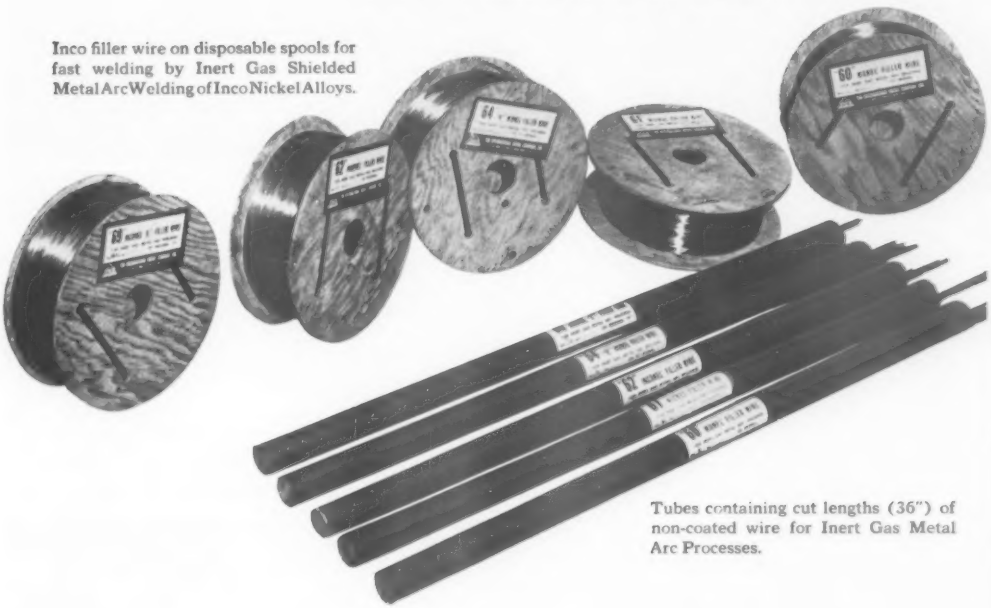
Introducing...

A COMPLETE LINE OF INCO FILLER WIRES ...FOR INERT GAS METAL ARC WELDING

Inco filler wire on disposable spools for fast welding by Inert Gas Shielded Metal Arc Welding of Inco Nickel Alloys.



Tubes containing cut lengths (36") of non-coated wire for Inert Gas Metal Arc Processes.

There's something new in filler wire for inert gas metal arc welding now.

Inco engineers have developed a special composition wire that will produce sound welds of the proper metallurgical balance on Inco Nickel Alloys.

Disposable spools of this new filler wire are available for any of the consumable electrode processes used to weld materials $\frac{1}{8}$" thick and over. (For tungsten electrode process Inco produces rods in cut lengths of 36", in sizes from 1/16" to 5/32".)

The spools are supplied in wire diameters of .035, .045, and .062 in the Inco "60" series of welding materials.

For inert gas metal arc welding of Monel® you should specify "60" Monel Rod or Filler wire, for Nickel specify "61" Nickel Rod or Filler wire, for Inconel® – "62", for "K"® Monel – "64", for Inconel "X"® – "69".

Of course, like other Inco Nickel Alloy materials, filler wire is on extended delivery now. That's because so much is needed for defense. Therefore, it will pay you to keep in touch with your distributor regarding available supplies.

To help you determine which Inco welding materials to use for specific applications, Inco's Technical Service Section has prepared a Welding Materials Guide. It covers welding solid materials, clad materials, dissimilar metals and overlays. You can get a copy by writing directly to Inco.

INCO TRADE MARK

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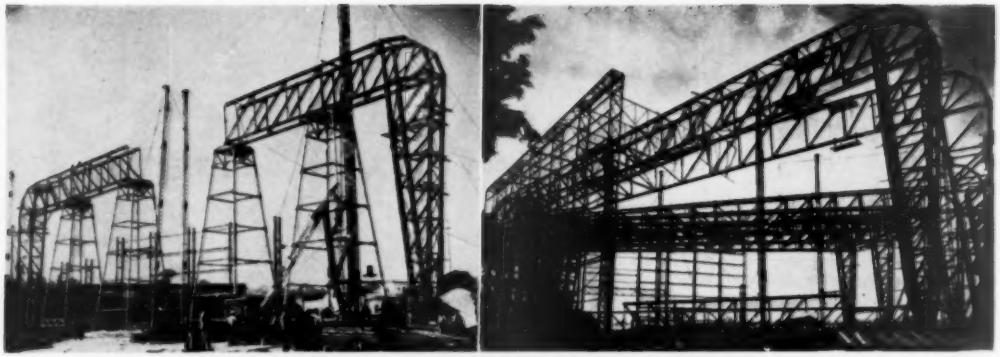

Welded Rigid Frame

to spend at least five weeks in this country. They will also participate in a special two-day productivity seminar now tentatively arranged at the Museum of Science and Industry on August 31 and September 1. At the seminar, discussions will be led by outstanding American engineering authorities. The Museum is headquarters for the Centennial and will be the scene of most of its major activities, some of which will begin early in July.

Following participation in the Centennial convocation, the foreign group will tour America's leading cities and production centers as well as other areas with key engineering installations. Main objectives will be to give them every possible opportunity to observe American methods of design, construction and operation of engineering works, mass production and distribution, and the roles of engineers, labor and management in the productivity of the United States.

Actual direction of the foreign engineering visitation will be conducted by the National Management Council, serving as an agent for the Mutual Security Agency.

Welded Rigid Frame

Long span, claimed to be the world's largest welded rigid frame, has a clear span of 328 ft. Mexico City's $4,500,000 new municipal auditorium has eight similar frames arranged in a pie shape. The auditorium, seating 18,500 people, is scheduled for completion this summer. The fabricators and erectors, Macomber de Mexico, state that a 50% weight saving was achieved by welded construction, lightness being essential because of the sandy subsoil condition. The 6000 tons of structural steel were welded with Lincoln Fleetweld 5 and 7. AWS class E6010 and E6012 electrodes.

"Red Head"
WELDING CLAMPS

• Designed for Welding •
No Threads To Damage

1. Case Hardened threads are always protected from weld spatter and never exposed to damage in open or closed position.

2. The clamp body is cut from solid plate, thereby insuring extreme rigidity and giving great resistance to bending or twisting.

3. Heat treated chrome molybdenum alloy handle offers great resistance to bending.

23 stock sizes

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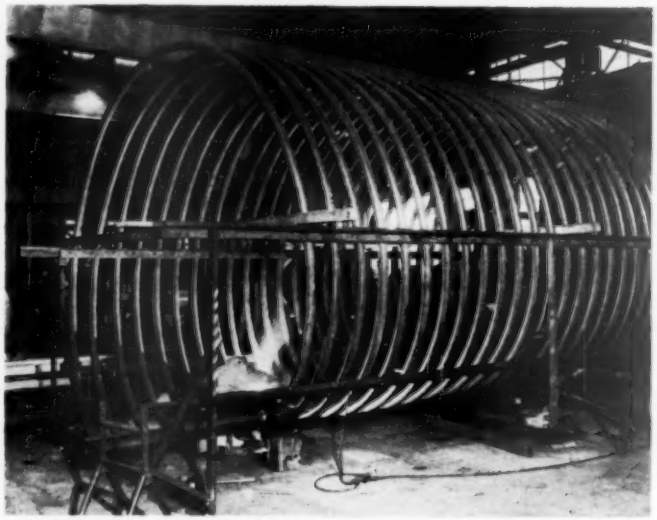
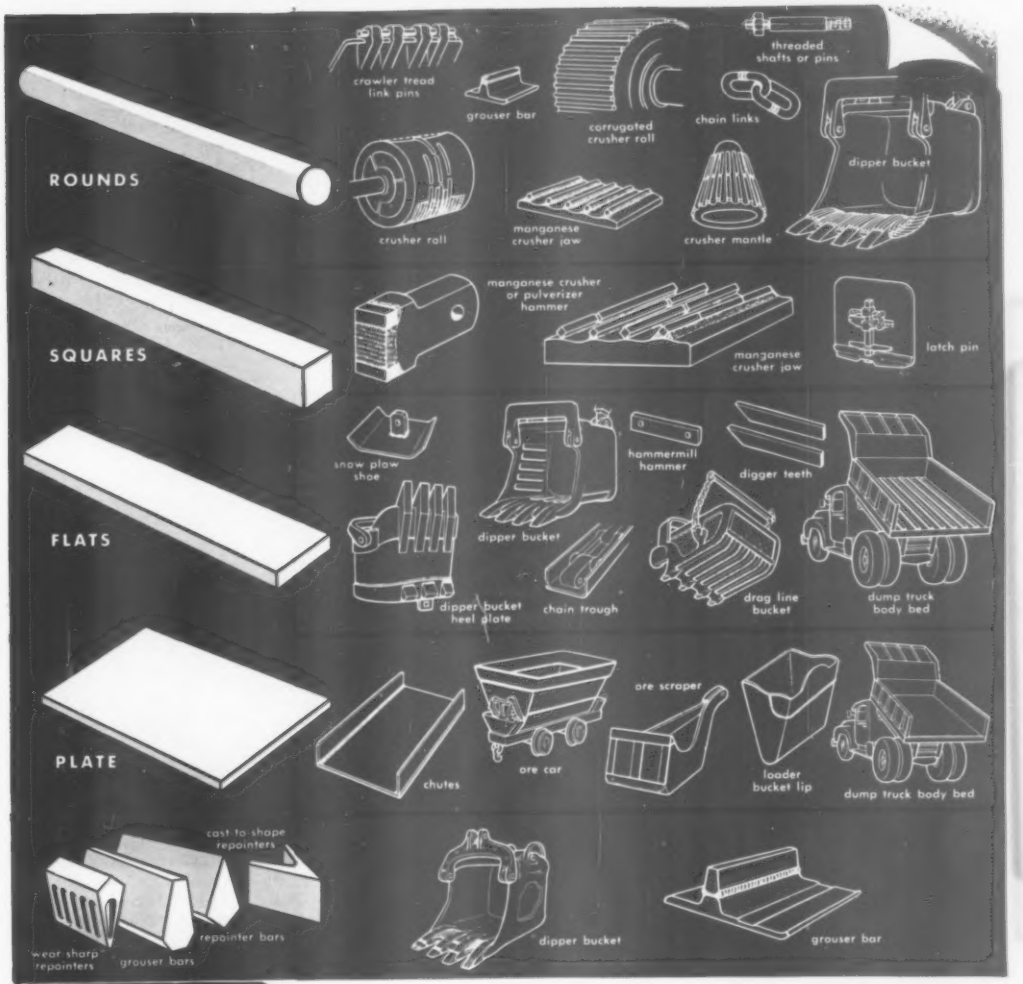


Photo courtesy General Electric Co.

Heating Coil

Twenty-foot lengths of extra-heavy, 3-in. seamless iron pipes are welded together and rolled to form this giant half-completed heating coil for the inside of a processing tank at the Newark, N. J., plant of the Steel and Alloy Tank Co. The firm fabricates heavy pressure vessels and process equipment to meet severe conditions of pressure, temperature and corrosion encountered in modern process industries. Above, a welder uses coated electrodes (AWS-E6012) for the root bead first welding pass which joins the pipe ends. Coated electrodes (AWS-E6010) are employed for the finish weld.

AMSCO MANGANESE STEEL WELDMENTS
ADD NEW LIFE TO WORN EQUIPMENT



Amsco Welding Rods and Electrodes
For repair welding of manganese steel shapes to worn equipment, American Manganese Steel Electrodes retain their toughness and give real operating savings.

Amscoating with Amsco Hardfacing Rods increases service life . . . reduces shutdowns.

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PERSONNEL

Named to Key Posts at Union Carbide and Carbon Research Laboratories

The appointments of Arthur R. Lytle as Director of Research, Walter Crafts as Associate Director of Research and David Swan as Assistant Director of Research of Union Carbide and Carbon Research Laboratories, Inc., have been announced by Dr. A. B. Kinzel, President. These laboratories are the primary metallurgical laboratories for Union Carbide and Carbon Corp. and carry on metallurgical research for Electro Metallurgical Co., Haynes Stellite Co., Linde Air Products Co. and other divisions of the corporation.

Mr. Lytle, who will move from Niagara Falls to New York, has been associated with the Union Carbide laboratories for 29 years. For the past two years, he has been responsible for all the metallurgical research activities there. Before then, he carried out and directed extensive research on the welding of metals. He developed many new welding rod compositions, including the first nonfuming bronze. Mr. Lytle also pioneered in the field of automatic welding machines, and was responsible for many advances in the use of the oxy-acetylene flame for hardening, powder-cutting and pressure-welding processes. He is a member of the American Society for Metals and the AMERICAN WELDING SOCIETY, and has presented numerous papers before both societies. He is a graduate of Rensselaer Polytechnic Institute.

The new Associate Director of Research, Mr. Crafts, has been Chief Metallurgist at the Niagara laboratories since 1946. Among the projects that he has handled has been the development of various alloy addition agents used in making steel and cast iron. His work on steelmaking and deoxidation, as well as on the hardenability and properties of alloy steels, has been described in many papers presented before the American Institute of Mining and Metallurgical Engineers and the American Society for Metals. Mr. Crafts is co-author of two books, one on *Hardenability and Steel Selection* and the other on *Alloys of Iron and Chromium*. He has degrees from both Yale University and Massachusetts Institute of Technology, and is widely recognized in the metallurgical profession as one of its leading scientists. He is a member of the British Iron and Steel Institute, as well as of most of the professional societies in the metallurgical field in the United States.

Mr. Swan, the new Assistant Director of Research, joined the Niagara laboratories in 1946. Recently, he has been in the New York offices as Research Engineer, but he will move back to Niagara Falls when he assumes his new responsibilities. His work has been concerned principally with special studies of the use of various alloys and metals used in making steel and cast iron. Mr. Swan has served on several metallurgical advisory committees, and is the author of several papers in the field of metallurgy and welding. Among the technical societies of which he is a member are the American Society for Metals, AMERICAN WELDING SOCIETY and the American Institute of Mining and Metallurgical Engineers. He graduated from Rensselaer Polytechnic Institute in 1940.

Weed Promoted

Henry D. Weed was elected vice-president and general manager of Weiger Weed & Co. He has been divisional manager of this subsidiary since 1947. Mr. Weed is a member of the AMERICAN WELDING SOCIETY.

Schiebel Promoted

Roy O. Schiebel, Jr., currently Midwest Manager of the Magnaflux Corp. in Chicago, Member AWS, will move to New York as Eastern Manager. Mr. Schiebel's experience includes weld engineering and 12 years of outstanding work with Magnaflux customers. He has previously managed the West Coast and Midwest sales offices of the company.

Carpenter Promoted

The appointment of Otis R. Carpenter, AWS member, of the Barberton, Ohio, works of The Babcock & Wilcox Co. as an executive assistant of the company has been announced by C. H. Gay, Vice-President.

A graduate of Allegheny College, with the master's degree in physics from the Case Institute of Applied Science, Mr. Carpenter began work with the B&W Laboratory at Barberton in 1933. The next year he was transferred to the Erection Department, working on the company's Gauley Bridge project from 1934 to 1935.

Following this, he returned to the Laboratory, and in 1947 was appointed director when the department was reorganized as the Works Control Laboratory.

Miller Electric Appointment

Miller Electric Manufacturing Co., Appleton, Wis., manufacturers of electric welding equipment, announces two new appointments to its official staff. A. E. "Tony" Harrant is now executive vice-president, and A. C. "Al" Mulder, vice-president in charge of production. Mr. Harrant was formerly office manager and has been associated with the company for the past five years. Mr. Mulder, an AWS Member, has been with the company for about twenty years in various capacities, including engineering, production and sales. Both are well known throughout the welding industry.

Pfeifer Made District Manager

Edmund Pfeifer, present district manager of sales in the Boston (Mass.) office of Lukens Steel Co., on June 1st will become district manager of sales of the New York office of the Company at 50 Church St., according to a recent announcement by J. Frederic Wiese, Vice-President in charge of sales.

Pfeifer, a native of Jersey City, N. J., and a graduate of Cornell University, has been associated with Lukens Steel Co. since 1939. He first joined the Lukens sales department in 1940 as an estimator, subsequently becoming an assistant in the Coatesville District Sales Office and, in 1945, a senior salesman therein. He was named assistant district manager of sales in the Boston office Apr. 1, 1949, and promoted to manager on June 11, 1950.

Al Drake Joins Burdett

The Burdett Oxygen Co. of Cleveland, Ohio, a leading manufacturer and distributor of industrial gases and welding and cutting equipment with branches throughout Ohio and California, has announced this week that Al Drake has joined their organization at their Dayton branch.

Mr. Drake, a graduate of the University of Washington in mechanical engi-

neering, welding and metallurgy, has been associated with Linde Air Products Co., where he was employed for eight years as a salesman, sale sengineer and process service engineer, and the Whitmore Oxygen Co., Salt Lake City, as a sales engineer.

Mr. Drake, who is a veteran of three years army service, was secretary of the Independent Oxygen Manufacturers Assn. and Vice-Chairman of the Salt Lake section, AMERICAN WELDING SOCIETY.

An avid and successful golfer, Mr. Drake has distinguished himself as a winner of several golf tournaments in Utah. He has also been active as district athletic director of the American Legion and as chairman of the Salt Lake Baseball Assn.

Mr. Drake is married and has one daugher, 3½ months old.

OBITUARY

Henry J. Miller

On Sunday, Apr. 27, 1952, death came to Henry J. Miller, Founder and President of the "Anti-Borax" Compound Co., Inc., of Fort Wayne, Ind., at the age of 89 years.

Mr. Miller received his early education at St. Paul's Catholic School in Fort Wayne and later at a business school in Chicago, Ill. He was a charter member of St. Patrick's Catholic Church in Ft. Wayne and a church trustee for more than a quarter of a century.

Mr. Miller was Vice-President and a Director of the Peoples Trust and Savings Co. of Ft. Wayne, as well as a Director of the Diester Concentrator Co. of that city. He was a Fourth Degree Knight of Columbus and also held memberships in many religious and fraternal associations and societies. He founded the Anti-Borax Compound Co., Inc., in the year 1906 and was active in its management until a few months before his death. He pioneered the manufacture and sale of "E-Z" Forge Welding Compound and later added "Anti-Borax" Fluxes for the Oxy-acetylene Welding Trade.

Mr. Miller is survived by his wife and three daughters and three sons. Two of the sons, Clement F. Miller and Paul E. Miller, continue to operate the company he founded.

Chas. M. Rusk

Chas. M. Rusk died at his home in Philadelphia on April 8th at the age of 62. The cause of death was attributed to a coronary occlusion. Mr. Rusk had been active in the AMERICAN WELDING SOCIETY in its early years and had served as the Chairman of the local section in 1933. He had been associated with the R. D. Thomas Co. from 1921 to 1933. From 1933 until 1941, he was with Horace T. Potts Co., and again between 1942 and 1944 he was employed by the Arcos Co. In 1944 he entered into his own business of welding equipment and supplies sales and had been active in it until his death. He is survived by his wife, Anna B. Rusk.

Clifton D. Welcomb

Clifton D. Welcomb, Technical Supervisor for the Detroit District of Air Reduction Sales Co., a Division of Air Reduction Co., Inc., and member of the AWS passed away on Mar. 6, 1952.

Mr. Welcomb, who was associated with Airco for many years, spent the early part of his career in railroad service. In this phase of the industry he pioneered many of the early welding applications that have since become standard operations on railway equipment.

He was well known throughout the Detroit metal working industries and was a recognized authority on the application of the oxy-acetylene processes.

Mr. Welcomb is survived by his wife and two children. His passing means the loss of a pioneer in the welding field and a personal loss to his many friends in Airco and in the industries he served for many years.

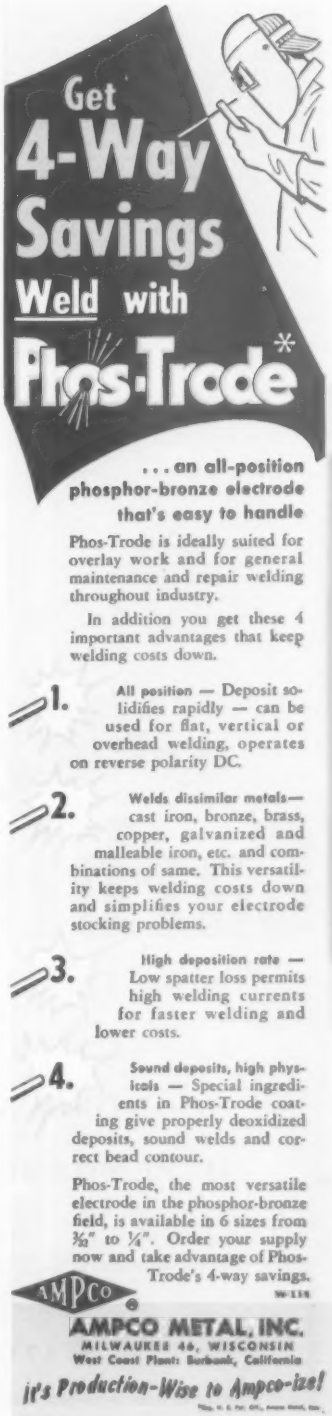
Percy C. Crittenden

Percy C. Crittenden, superintendent of the welding department of the American Shipbuilding Co., and a member of the AWS since February 1941, collapsed of a heart attack while attending a symposium dinner meeting of the AWS Cleveland Section on May 9th and was pronounced dead on arrival at Charity Hospital.

Mr. Crittenden had been connected with the American Shipbuilding Co. for the past 25 years. The Company has sustained a very severe loss in his passing. His knowledge of welding from a standpoint of both theory and application will be difficult to replace.

The Lorain yard of the American Shipbuilding Co. holds an outstanding postwar record. About 14 hours after his death another lake giant, the *Philip Clarke*, cleared the Lorain harbor on a trial run. The *Arthur Anderson*, sister ship of the Clarke, will soon join the Pittsburgh Steamship Co. fleet. Mr. Crittenden had witnessed the completion of the *Clarke* and saw the *Anderson* reach the final stages.

Although shipbuilding work crowded


Get
4-Way
Savings
Weld with
Phos-Trode*
. . . an all-position phosphor-bronze electrode that's easy to handle
Phos-Trode is ideally suited for overlay work and for general maintenance and repair welding throughout industry.
In addition you get these 4 important advantages that keep welding costs down.
1. All position — Deposit solidifies rapidly — can be used for flat, vertical or overhead welding, operates on reverse polarity DC.
2. Welds dissimilar metals — cast iron, bronze, brass, copper, galvanized and malleable iron, etc. and combinations of same. This versatility keeps welding costs down and simplifies your electrode stocking problems.
3. High deposition rate — Low spatter loss permits high welding currents for faster welding and lower costs.
4. Sound deposits, high physicals — Special ingredients in Phos-Trode coating give properly deoxidized deposits, sound welds and correct bead contour.
Phos-Trode, the most versatile electrode in the phosphor-bronze field, is available in 6 sizes from 3/32" to 1/4". Order your supply now and take advantage of Phos-Trode's 4-way savings.
W-114
AMPCO
AMPCO METAL, INC.
MILWAUKEE 46, WISCONSIN
West Coast Plant: Burbank, California
It's Production-Wise to Ampco-ize!

his days, Mr. Crittenden still found time to be prominent in civic and educational affairs. He was active in promotions of the Lorain Chamber of Commerce and was a past president of the Clearview Board of Education of which he had been a member five years.

He was active in the AWS Cleveland Section and was also a member of the Naval Architects and Marine Engineers. He was a veteran of World War I where he served in a tank division.

He is survived by his wife, Margaret; two sons, John Carver Crittenden and George Robert Crittenden of the U. S. Naval Air Corps, Pensacola, Fla.

Frank C. Fyke

Born in West Unity, Ohio, and a graduate of Ohio Northern University, Mr. Fyke was associated with the Standard Oil Development Co. and its predecessor organizations for almost 34 years.

As head of the Materials Inspection and Expediting Division of its Esso Engineering Department, he was chiefly responsible for the growth and development of this inspection service to all affiliates of Standard Oil Co. (New Jersey). During part of this period he was also director of the Materials Testing Laboratory.

He participated in the technical activities of National Societies and served on many committees among which were: ASME Boiler Code—Subgroup on Qualification of Welding Inspectors; ASME Boiler Code—Special Committee on Radiographic Examination of Welded Joints; ASTM—Committee A-1 on Steel and Low Temperature Advisory Committee, Committee E-7 on Radiographic Testing; AWS—Committee on Methods of Inspection; Joint AWS-ASTM—Committee on Filler Metal Specifications; Welding Research Council—Pressure Vessel Research Committee. He was also District Vice-President, AMERICAN WELDING SOCIETY 1943–45.

He was keenly interested in the development of sound welding practice among the foreign and domestic affiliates of Standard Oil Co. (New Jersey). He organized the first annual Welding Forum conducted by the Esso Engineering Department for these affiliates and had been chairman and coordinator of this work for the past 15 years.

In addition to his professional work, he was interested in the local civic affairs and at the time of his death on May 10th was President of the Republican Club in his home town of Cranford, N. J.

He is survived by his wife and a son Frank C. Fyke, Jr., of Roselle, N. J.

National
Carbide
IN THE RED DRUM
EFFICIENT
ECONOMICAL
DEPENDABLE

FOR WELDING and CUTTING
Use National Carbide in the Red Drum
Write us for information as to nearest available stock.
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A Division of Air Reduction Co., Inc.

FLOWLINE
.237" WALL
316
MADE
BY
SPECIALISTS
in
Stainless Steels,
Monel, Nickel
The FLOWLINE Elbow
TRADE MARK
FLOWLINE Fittings are made by specialists having more experience with corrosion-resistant piping than any other fitting manufacturer. Our exclusive process of cold forming and annealing produces fittings in the best condition for corrosion service. The use of FLOWLINE Fittings makes available to users of corrosion-resistant piping the efficiency and economy of simplified welded construction.
The FLOWLINE Ell is typical. Its long radius and smooth interior walls assure full effective sweep, reduce pressure loss, minimize flow resistance, corrosion, erosion, and product accumulation. The ell is round and ends are accurately machine tool cut and finished, making it easy to fit to pipe.
FLOWLINE Welding Fittings—tees ells, reducers, stub ends, and caps—are made and normally stocked in Schedules 5, 10, 40, and 80—sizes ½" through 12"—in stainless types 304, 316, 347; Monel, Nickel. All fittings are annealed, cleaned bright — stainless fittings are passivated — and marked with type of metal, heat number, size, schedule, and wall thickness.
WELDING FITTINGS CORP.
NEW CASTLE, PENNSYLVANIA
World's Largest Manufacturer of Stainless Welding Fittings

NEW PRODUCTS

Spooled Aluminum Wire

Spooled aluminum wire for use in the inert-gas shielded metal-arc welding of aluminum is manufactured by Weldwire Co., Inc.

Aluminum alloy wires such as 28, 43S and 52S are triple-cleaned of all surface contaminants and oxides and are precision layer-level wound on 10-lb spools. Surface cleanliness guarantees weld metal of sound, X-ray quality. Precision spooling insures uninterrupted wire feed through welding apparatus.

All Weldspool wires meet strict quality control standards. Controlled chemistry insures right metallurgy. Standards for wire temper added to complete de-kinking and precise layer-level winding provide smooth wire feed.

Technical information on the use and applications of the Weldspool aluminum welding wires is available by writing to Weldwire Co., Inc., N. W. cor. Emerald & Hagert Sts., Philadelphia 25, Pa.

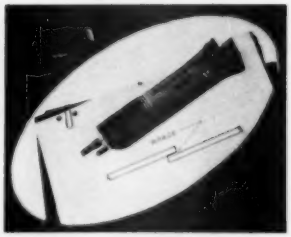
Phos-Copper Brazing Alloy Available in Paste Form

Phos-Copper®, a free-flowing brazing alloy with a low melting point for brazing operations on copper and copper alloys, is available in paste form from Westinghouse Electric Corp.

An alloy of copper and phosphorus, Phos-Copper's fluidity and wetting properties provide good capillary action that enables it to penetrate tight-fitting joints instantly to form a strong, ductile bond. On most copper applications, no flux is required.

The new brazing paste is finely powdered Phos-Copper suspended in a petroleum jelly. A small amount of this paste placed between the pieces being joined takes the place of a brazing rod, and the joint need only be heated until the brazing filler metal flows. It is designed for resistance brazing where it can be conveniently preplaced and is packaged in collapsible 1-lb tubes and in 5- and 30-lb cans.

This brazing alloy also is available in rod and wire sizes from $^1/_{16}$- to $^1/_4$-in.



Phos-Copper paste in collapsible tube form

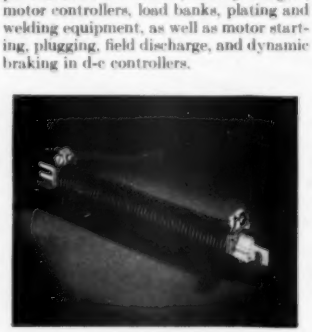
diameter and in rings and strips (for making special shapes).

For further information write Westinghouse Electric Corp., Box 2099, Pittsburgh 30, Pa.

Powr-Rib Resistors for High-Current Use

Powr-Rib, a new edgewound-type resistor, designed for high-current duty in both intermittent and continuous applications, has just been announced by Ohmite Manufacturing Co., 4823 Flournoy St., Chicago, Ill. The new resistor offers high heat dissipation, resistance to oxidation and the ability to withstand shock and vibration without breaking or shorting.

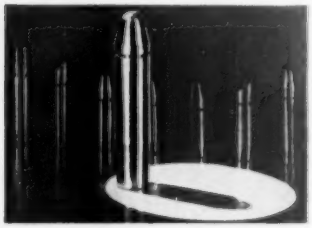
Ohmite Powr-Rib resistors are suitable for original equipment or for replacement in existing installations, where high-current and good heat-dissipating characteristics are required. They are particularly applicable in electric trucks, battery chargers, motor controllers, load banks, plating and welding equipment, as well as motor starting, plugging, field discharge, and dynamic braking in d-c controllers.



The resistors are wound with a heavy ribbon of resistance alloy on a ceramic insulator. All other metal parts are specially plated to prevent oxidation at high operating temperatures and to provide good electrical contact. The ceramic insulator is divided into five sections to give the required flexibility and resistance to shock and vibration.

Spot-Welding Electrode

The Kaptrode resistance-welding electrode, announced last winter by Weiger Weed & Co., division of Fansteel Metallurgical Corp., 11644 Cloverdale Ave., Detroit 4, Mich., is now available in No. 3 Morse taper sizes as well as No. 1 and No. 2.

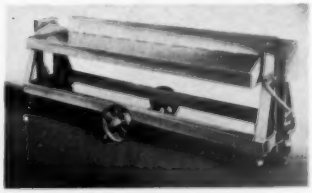


This is an expendable cap-type electrode which fits into a semipermanent adapter shank, which in turn fits any standard electrode holder of No. 3 Morse taper size. The electrodes are made in six nose styles, including pointed, dome, flat, offset, truncated cone and radius face, and in three RWMA alloys (Classes 1, 2 and 3). Adapter shanks are made in six lengths, ranging from $1^3/_4$ to 3 in. All styles of electrodes fit interchangeably into any shank, projecting 1 in. from the shank. With the proper shank length, therefore, it is possible to duplicate standard electrode lengths, making it unnecessary to change established machine setups.

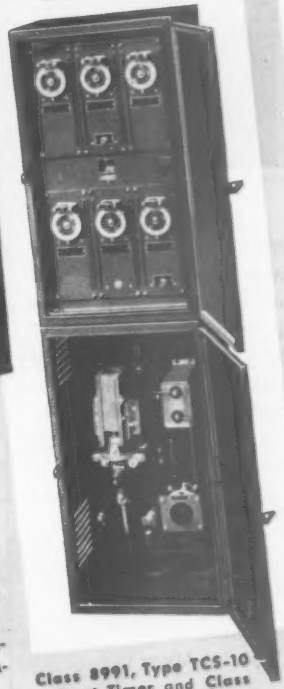
Tilt Top Truck

Because, in one case, 2000-lb broach holders could be handled only by crane, and because the crane could deliver the broach holder in only one manner, a means was required for positioning the broach holder for certain maintenance operations. This Portelvator Tilting Top Truck was constructed to meet the need.

The table top, 24 x 96 in., rotates 360 deg on a horizontal axis and can be locked in place wherever stopped. Back plate supports broach holders and fixtures as table tilts work to convenient position for service. Table service is 30 in. from floor. Truck rides on two wheels and four casters for easy maneuverability in restricted



Specify.. SQUARE D Safront RESISTANCE WELDER CONTROL



FOR CONTINUOUS PRODUCTION—heavy duty rugged construction, hardened moving parts, and accurate, dependable pneumatic timer units.

FOR OPERATOR SAFETY—Safront panel construction isolates individual timer adjustments from live parts. Transformer provides 110 volts for all control circuits.

FOR MOUNTING FLEXIBILITY—Dimensions are standardized. Timers and contactors can be mounted in four different positions for wall or machine mounting.

FOR LOW INSTALLATION COST—Matching knockouts permit close coupling of enclosures, eliminating need for conduit run between contactor and timer.

FOR SIMPLIFIED MAINTENANCE—Accessible mechanical parts and easy coil replacement reduce "down" time and maintenance costs.

Class 8991, Type TCS-10 Safront Timer and Class 8990, Type SCG-2 Syncro-Break Contactor arranged for wall mounting. The same size, neat appearing enclosure is used for 4 and 6 period Safront timers and sizes 1W and 2W Syncro-Break contactors.

When extreme precision or speed is required—use Square D's Electronic Welder Control. Write for Bulletins 8990-8993 which detail the complete Square D line, magnetic and electronic. Address Square D Company, 4041 N. Richards Street, Milwaukee 12, Wisconsin.

SQUARE D COMPANY

Weldwire Company, Inc.

formerly Weldit Wire Co., Inc.

WIRE FOR WELDING SUPPLIES FOR WELDING

WELDSPOOL 347

WELDSPOOL 347 and other stainless grades are processed and precision spooled for the "INERT GAS METAL ARC WELDING" of JET ENGINE ASSEMBLIES and other critically engineered applications.

WHEN WELDING:

Aluminum
Stainless Steels
Alloy Steels
Bronzes, or
Special Alloys

WHERE QUALITY IS A FACTOR, USE

"WELDBEST" Welding Electrodes
"WELDWIRE" Welding Rods
"WELDSPOOL" Electrode Wire

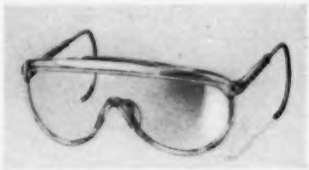
WELDWIRE COMPANY, INC.
N.W. Cor. Emerald & Hagert Sts.
Philadelphia 25, Pa.

space. Floor locks at each end prevent unwanted movement. Capacity is 3000 lb.

This Portelvator Tilting Top Truck may be built to alternate specifications. For additional information write the manufacturer, The Hamilton Tool Co., Hamilton, Ohio.

Safety Goggle

A new safety goggle, featuring a transparent plastic frame which provides a greater field of vision, is announced by American Optical Co., Southbridge, Mass.



The new goggle is designed and recommended for wear directly over the eyes or over spectacles. It is particularly useful for frontal protection against foreign particles on machine and hand tool work, bottling, chemical and physical laboratory work, spot welding, light grinding, light chipping and light riveting.

New Brazing Alloy

A new copper-phosphorus-silver alloy, Phos-Silver®, for efficient brazing of copper, brass and bronze, is available from the Westinghouse Electric Corp. Extreme fluidity and good wetting properties enable this new alloy to penetrate tight-fitting joints instantly to form strong ductile bonds.

Torch-brazing with Phos-Silver® rod

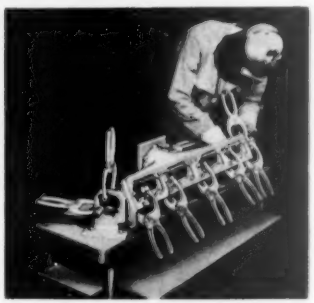
Phos-Silver® can be used with any of the common brazing methods for brazing on copper or copper alloys, and is ideally suited for applications where brazing temperatures are critical. On heavy sections that absorb large quantities of heat, its low brazing temperature (1225–1275° F) substantially reduces brazing time. On fine work or low-melting brass, where there is danger of overheating, it provides an extra margin of safety. No flux is needed in copper-to-copper brazing.

Typical Phos-Silver® uses are found in the assembly of refrigerating and air-conditioning equipment, motors and transformers and heat exchangers and plumbing installations.

For further information, write Westinghouse Electric Corp., Box 2099, Pittsburgh 30, Pa.

Clamps Adapted to Welding Fixture

A unique welding fixture utilizing De-Sta-Co portable toggle clamps has been designed by the Steel Cooperage Division of the Serrick Corp. The fixture holds four rectangular- and three round-engine manifold flanges to an alignment plate during an inert-arc-welding operation prior to final stainless steel welding. A "V" type prong replaces one clamping jaw on three of the twelve model No. 468 portable toggle clamps used, to provide additional gripping area on the manifold stamping. Precise alignment is important because the flange openings must fit on machined engine block studs.



After the tack weld application the manifolds are transferred to the final operation, where the flanges are arc welded with stainless steel rod. The manifolds are part of Ford engines which are replacing worn-out equipment in the reconditioning of Sherman tanks. Approximately 54 manifolds are completed per fixture during an 8-hour shift.

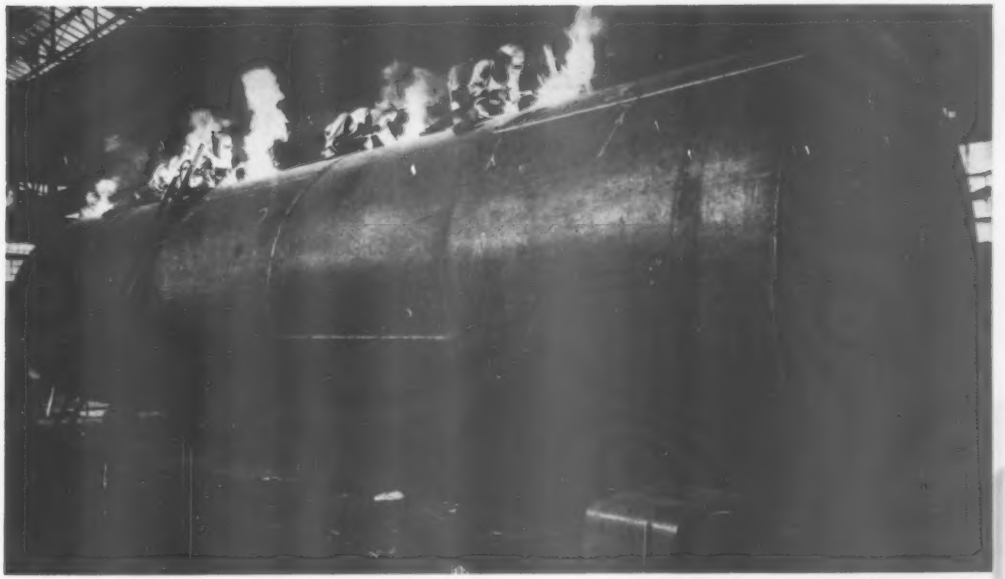
The De-Sta-Co toggle clamps are manufactured by the Detroit Stamping Co., 322 Midland Ave., Detroit 3, Mich.

Metal Cleaner

How a new metal cleaner, Oakite Compound No. 31, cleans, derusts and phosphates in a single operation is described in a special brochure available from Oakite Products, Inc., New York, manufacturers of industrial cleaning and related materials.

Oakite Compound No. 31, the manufacturers report, is a highly concentrated, liquid detergent which can be diluted up to 25% by volume for economical prepaint treatment of metal by dipping or hand-swabbing methods. Besides preparing metal for paint, Oakite Compound No. 31 has detergent properties that effectively remove light soils as well as soldering and welding fluxes, the brochure states.

Readers wishing additional details of this new prepaint cleaner may obtain free copies of the descriptive brochure by writing on company letterhead to Oakite, Products, Inc., 118F Rector St., New York 6, New York.



WORTHINGTON TURNING ROLLS IN OPERATION move this big tank at exactly the right speed for the most efficient downhand welding. This equipment often increases output as much as 50% because downhand welding with heavier electrodes does the job with one pass instead of two or three.

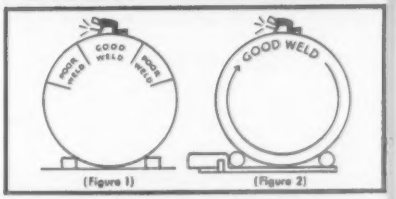
A way to lower your welding costs as much as 50%

If you are welding cylindrical vessels of any size, you can lower costs and increase welding footage as much as 50% with Worthington Turning Rolls.

Your welders can produce more *real footage* by eliminating time wasted in manually turning the vessel or waiting for crane or hoist service.

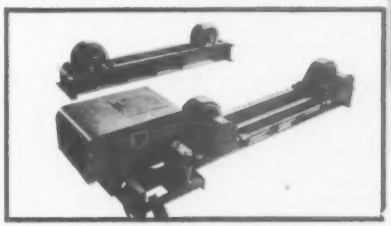
You'll get neater, stronger welds and less rod waste, too. The Worthington Turning Roll power turns the vessel at selected welding speeds for quickest spotting of longitudinal seams and continuous welding of circumferential seams. All welds can be made by the convenient downhand method with the economies that result from larger electrodes used.

Where can you see a Worthington Turning Roll at work near you? Just write Worthington Corporation, formerly Worthington Pump and Machinery Corporation, Dunellen, N. J., for this information or for Bulletin 210C.



WHY WORTHINGTON TURNING ROLLS INSURE BETTER WELDS

Unless the work is turned continuously, good downhand welding is obtainable only in small area (Fig. 1). With a Worthington Turning Roll, downhand welding is assured for the complete circumferential seam (either by manual or automatic welding) (Fig. 2).



WORTHINGTON'S LOW-SLUNG DRIVE MECHANISM permits unobstructed loading from either end of turning rolls. The high-efficiency and smooth operation of Worthington power rolls (lower right) and idler rolls (upper left) result from long and varied experience in building equipment for welding cylindrical vessels.

Y.I.3

WORTHINGTON

Welding Positioners
Turning Rolls

NEW LITERATURE

Gun Welder Pamphlet

The A. P. Seedorff & Co., Inc., 6230 Maywood Ave., Bell, Calif., has issued an attractive 4-page pamphlet describing various types of portable spot-welding guns manufactured by this company and how they operate.

Hobart Arc Welding News

Volume IX, No. 1, *Hobart Arc Welding News*, a 16-page booklet of interesting photographs and articles on welding from all over North America, is now available. Copies are mailed free of charge to anyone interested in welding. Many of the articles feature time-and-money saving applications.

To get your copy, write the Hobart Brothers Co., Troy, Ohio.

Preheating

A reprint of "Preheating for Welding" by Arthur B. Tesmen which appeared in the April 1952 issue of THE WELDING JOURNAL is available free of charge to our readers who request them on their business stationery from Tempil® Corp. 11 W. 25th St. New York 11, N. Y. This paper reviews welding procedures which have been found by experience to produce crack-free welding joints under a wide variety of conditions.

Graphitization Research Study

A 12-page booklet just published by Edward Valves, Inc., East Chicago, Ind., comprehensively discusses the graphitization phenomena encountered in systems operated at elevated temperatures in the power and processing industries.

Based on an intensive research program in the Company's laboratories, which has extended over the last ten years, this research study describes in detail the nature of graphitization and its effects, and lists preventive and corrective measures. Profusely illustrated with photomicrographs of metallurgical specimens illustrating the graphitization process, the booklet also contains eutectic diagrams and graphs illustrating the effect of temperature, time and other variables on graphitization. Separate sections in the article cover the effect of chemical composition, deoxidation practice, prewelding microstructure, welding conditions, stress and strain.

Advance copies of the booklet distributed to industry leaders have been enthusiastically received. Copies of the study may be obtained by writing to Department GA, Edward Valves, Inc., East Chicago, Ind.

New Welding Accessories Catalog

A new 44-page Catalog No. 24 of The Fibre-Metal Products Co., Chester, Pa., has been published, showing a large diversified line of welding helmets, hand shields, electrode holders (for electric and carbon arc), weld cleaning hammers, scratchmaster brushes, weld testing machines, protective clothing and welding cable.

In addition it contains many new items such as helmet stop, insulated friction joint, combination skullguard and face shield, headrest welding goggles, special-purpose welding helmets and industrial safety masks (both screen and chrome leather), "Monarch" and coated cover glass, general-purpose safety helmet, together with many others.

This catalog is being distributed throughout the United States and foreign countries by the company's representatives. Contact your nearest distributor or write direct for your copy.

ASTM Specifications for Steel Piping Materials

The 1952 edition of this compilation sponsored by ASTM Committee A-1 on Steel contains, in their latest approved form (as of late February), the 56 widely used ASTM specifications for carbon-steel and alloy-steel pipe and tubing, including stainless.

Materials covered include: pipe used to convey liquids, vapors and gases at normal and elevated temperatures; still tubes for refinery service; heat exchanger and condenser tubes; boiler, superheater and miscellaneous tubes. To make the volume more complete there are also included specifications for the following materials used in pipe and related installations: castings; forgings and welding fittings; bolts and nuts. The ASTM standard classification of austenite grain size in steels (E19) with two sets of charts; also the American Standards covering wrought steel and iron pipe (B36.10) and stainless steel pipe (B36.19) are a part of the book.

New specifications cover: seamless and welded steel pipe and tubes for low-temperature service; seamless ferritic alloy steel pipe for high-temperature service; forged or rolled carbon and alloy steel flanges, forged fittings, and valves and parts for low-temperature service; ferritic and austenitic steel castings for high-temperature service; ferritic steel castings for pressure containing parts suitable for low-temperature service.

Numerous Emergency Alternate Provisions applying to specifications in this compilation have been issued and are furnished with this volume. (These Emergency Alternate Provisions are issued by the American Society for Testing Materials in accordance with a special procedure in the interest of expediting procurement or conservation of materials during the period of National Emergency. They are intended for use where they may be considered by the purchaser of the material as a permissible alternate for the specific application or use desired.)

This book is of distinct service to those concerned with pressure piping, power generating, the petroleum field, the distribution of gas, oil, water, etc., and to individuals in every industry where these materials are important.

Copies of this 384-page publication, in heavy paper cover, can be obtained from American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., at $3.50 each.

Practical Radiography for Industry

Unique in its practical, how-to-do-it approach, this useful volume by H. R. Clauser provides radiographers, inspectors, metallurgists, engineers, technicians—in fact, anyone concerned with the nondestructive testing of materials—with concrete working information on modern radiographic techniques.

Here, with the aid of nearly 200 illustrations, including sample radiographs showing actual defects in metal parts, you will find detailed information on set-up procedures, exposure factors and techniques, radiograph quality, films and films processing in addition to a complete coverage of radiograph interpretation, the identification of defects and discontinuities in various materials and discussions of applicable standards.

Separate chapters are devoted to radiography with radium and Cobalt 60, fluoroscopy and miscellaneous applications including such recent advances as radiation detectors, microradiography and thickness-gaging methods. Latest information is also presented on high voltage radiographic techniques using 1-, 2-, 10- and 22-million volt X-ray equipment.

Practical Radiography for Industry is directed primarily to those who actually perform radiographic inspections and to those who read or interpret radiographs and evaluate their findings. However, equipment and fundamental principles are treated in a concise, relatively nontechnical manner thoroughly understandable even to those with little or no training in physics or mathematics.

The price of this book is $7.50. It was published by the Reinhold Publishing Corp., 330 W. 42nd St., New York, N. Y.

ANACONDA-997

(Low Fuming) Bronze Rod

"keeps our customers happy"

—says W. L. Marple, owner of Marple's Welding & Machine Shop, Denver, Colorado

"This gland is used with a ram on a hydraulic press. We built up the inside by braze-welding. Then we machined it to very close tolerances. AnacondA-997 (Low Fuming) Bronze Rod was so successful that our customer complimented us on our ability to handle this unusual repair weld in such an economical way."

"We're mighty pleased with ANACONDA Rods and have used them on every metal I can think of. Castings have to be heated only to a cherry-red, so there's less chance of warping or cracking the work.

"ANACONDA Rod 'tins' easily, too. The welds are strong but easy to machine. Because ANACONDA Rod flows better, I get *more* welds with it. The salesman from M. L. Foss, Inc., Denver, Colo., our Anaconda supplier, gives us a lot of help and has been able to supply us with rod for all types of work. He's a good welder himself."

ANACONDA Rods for both electric and oxyacetylene welding are available from distributors throughout the United States. For the latest information on welding techniques write for free booklet B-13, The American Brass Company, Waterbury 20, Connecticut. In Canada: Anaconda American Brass Ltd., New Toronto, Ontario. 52174

Mr. Marple, Joe Boanik, foreman, and Charles Hunter, welder, load copper molds for a local manufacturer. Marple designed a special way to weld bronze backs on these molds with AnacondA Rods. Now he handles all this company's welding!

braze or weld with confidence—

ANACONDA® *welding rods*

ANACONDA

an ACCO product for Stainless Steel WELDING

AC-DC Electrodes

GAS Welding Rods

made by PAGE

BURNING...
stable even at lower heats

SLAG...
clean, easily removed

COATING...
resists cracking down to very short stubs

SELECTION...
complete line for welding every type of stainless

Get in touch with your PAGE distributor

ACCO

PAGE STEEL AND WIRE DIVISION
AMERICAN CHAIN & CABLE

Monessen, Pa., Atlanta, Chicago, Denver, Detroit, Los Angeles, New York, Philadelphia, Portland, San Francisco, Bridgeport, Conn.

PAGE Welding Electrodes AND Rods

Mechanical Properties of Metals at Low Temperatures

National Bureau of Standards Circular 520, 206 pages, 129 figures, 50 tables, $1.50 (order from Government Printing Office, Washington 25, D. C.).

Many mechanical devices and equipment operate at low temperatures; and the consequent embrittlement of materials, accompanied by brittle failures, is of concern to designers, manufacturers and users. The subject continues to increase in importance with the steady growth of the refrigeration industry and the expanding demand for the liquefaction, transportation and storage of many gases.

This volume presents results of studies conducted both in industry and in government to further knowledge of the behavior of metals at low temperatures, which is important to an understanding of their fundamental rheological properties. The papers were initially presented at the Symposium on the Influence of Low Temperatures on the Mechanical Properties of Metals held at the National Bureau of Standards on May 14 and 15, 1951, during the 50th anniversary of the founding of the Bureau.

Papers included in the volume cover recent European work in the field; manufacture of steels, development and application of chromium-copper-nickel steel and application of metals in aircraft for low-temperature service; tensile properties of copper, nickel and some copper-nickel alloys, properties of austenitic stainless steels and mechanical properties of high-purity iron-carbon alloys at low temperatures; dimensional effects in fracture; and brittle fractures in ship plates.

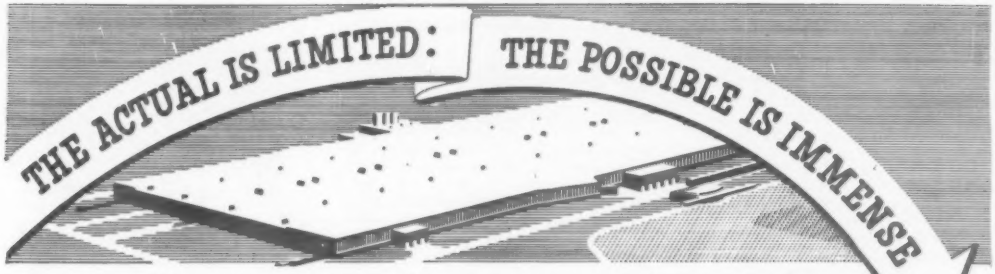
Basic Engineering Metallurgy

This book of 384 pages, by Carl A. Keyser, is published by Prentice-Hall, Inc., 70 Fifth Ave., New York 11, N. Y., and sells for $8.00. It is intended to serve, primarily, students in all branches of engineering. The book also contains general metallurgical information of interest to engineers specializing in materials and methods.

The first six chapters approach the subject from a theoretical viewpoint. In these chapters are presented the concepts and principles of behavior common to most metals. Discussed in this connection are the mechanism of metal failure and the steps that can be taken to improve service behavior.

Chapters 7 through 9 are devoted to the properties and heat treatment of steel. These topics are probably among the most important phases of engineering metallurgy. Chapters 10 through 12 present a discussion of the properties, applications and fabrication of some nonferrous metals.

Chapters 13 through 18 discuss the advantages, limitations and control of the various means of fabricating metals. Casting, electroforming, and powder metallurgy techniques are discussed as primary methods of fabrication, i.e., methods by which formless metal is made into useful



NEW LINCOLN PLANT CREATED BY INCENTIVE-INSPIRED CO-ACTION IN DEVELOPING POSSIBILITIES IN PRODUCT

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HOW TO ESTIMATE SAVINGS WITH STEEL

THE table (Fig. 3) provides a rule-of-thumb comparison on which to estimate savings with welded steel. The figures shown are based on shop costs of $2.00 per hour and 200% overhead. Welded steel designs that do not already average 50% savings can be analyzed similarly to detect excessive fabricating expense.

Fig. 2—"Equivalent Sections in Steel" using good shaping practices are:

TYPE OF LOAD	DESIGN NEED	AMOUNT OF STEEL AREA NEEDED TO REPLACE IRON SECTION
Tension	Rigidity	40%
	Strength	25%
Compression Short Column	Rigidity	40%
	Strength	90%
Compression Long Column	Rigidity	35%
	Strength	35%
Bending	Rigidity	35%
	Strength	20%
Torsion	Rigidity	35%
	Strength	25%

Fig. 3

CASTING		WELDMENT			
		EQUIVALENT MATERIAL DESIGN		50% EXCESS MATERIAL DESIGN*	
AVERAGE DESIGN		50% Cost Reduction	25% Cost Reduction	50% Cost Reduction	25% Cost Reduction
Weight (lbs.)	Cost ($)	Allowed Labor Time (hours)		Allowed Labor Time (hours)	
10	1.60	.11	.17	.09	.16
20	3.20	.22	.35	.18	.32
40	6.40	.43	.70	.36	.63
60	9.60	.65	1.05	.55	.98
80	12.80	.70	1.40	.73	1.27
100	16.00	1.17	1.75	.92	1.59
200	32.00	2.27	3.50	1.83	3.17
300	48.00	3.25	5.25	2.75	4.75
500	80.00	5.42	8.75	4.60	7.90
700	112.00	7.60	12.25	6.40	11.10
1000	160.00	10.85	17.50	9.15	15.80
1500	240.00	16.25	25.40	13.75	23.80
2000	320.00	21.70	35.00	18.35	31.70
2500	400.00	27.10	43.70	22.90	39.50
3000	480.00	32.50	52.50	27.50	47.50

* Products with design sections having 50% more steel than equivalent needed to carry loads.

HOW TO DESIGN IN WELDED STEEL—Complete training course for designers and production engineers now available for presentation in your plant. Send for complete details.

PROPER DESIGN IN STEEL IMPROVES PRODUCT CUTS COST 50%

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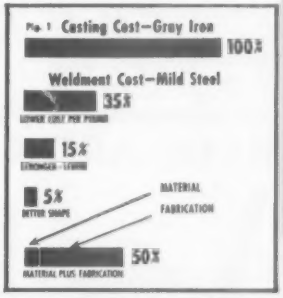
Replacing cast iron with steel on a pound-for-pound basis, without changing product shape, cuts material costs 63%. Then, by using the right amount of steel and still without changing product shape, 60% to 75% of the metal can be eliminated and material costs reduced to 15%. Ultimately utilizing a more efficient product shape, possible only with steel, reduces material cost to as low as 5%.



Most production savings are achieved on product conversions where simply the correct amount of steel or "equivalent section in steel" is incorporated into the design (Fig. 2). The chart (Fig. 3) shows how much fabricating is possible on such conversions to maintain overall production savings averaging 50%.

HOW TO SAVE 50%

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solid shapes. These solid shapes are further processed into useful objects by secondary methods of fabrication which include mechanical working, joining, machining, finishing and electroplating.

Improved Submerged Arc Welds

Fixing the cooling rate of welds made in medium alloy steels by the submerged arc process, to improve ductility and control grain growth, is covered in a new booklet, *Predetermination of Preheat and Postheat for Submerged Arc Welding*. Included in this booklet are the results of bend tests of weld beads deposited without preheating or postheating. These are compared with results of similar tests made with preheating and postheating for varying times and at various temperatures. The effect of increased carbon and alloy content on transformation of the steel is also discussed.

Diagrams are included to show the time-temperature relationship for complete isothermal change in twenty-four grades of SAE steel. A table suggests postheat times and temperatures for these steels. Many other tables, diagrams and pictures illustrate the booklet.

You may obtain this booklet free from any Linde office or by writing direct to Linde Air Products Co., a Division of Union Carbide and Carbon Corp., 30 E. 42nd St., New York 17, N. Y.

New McKay Manual

The Electrode Division of The McKay Co. announces the publication of a new manual which describes the procedure for welding mild and low-alloy steels and gives complete information about the electrodes available for such welding.

Specifications, operating characteristics, mechanical properties, uses and other essential data on all McKay mild steel, low-alloy and special-purpose electrodes are clearly and briefly presented. The "Quick Selection" charts make it easy to find the exact McKay electrode for every fabrication and maintenance welding requirement.

A second section of this manual is devoted to the McKay electrodes especially designed for hard surfacing and repair welding in such applications as railroad switch points, frogs and crossings; building up worn parts on earth-moving equipment and burnishing rolls; shear blades, tools and dies, punching and cutting tools. In the same section, electrodes for cast-iron welding are fully detailed.

The welding engineer, welding supervisor and the welder will find this handbook complete and comprehensive. For sales, purchasing and service personnel it will serve as a useful guide on the entire subject of welding mild and low-alloy steels.

For a copy of the handbook *The Welding of Mild Steels*, write to The McKay Co., 303 McKay Building, Pittsburgh 22, Pa.

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...Reduced arc blow
...Completely adjustable by operator

Westinghouse RA Welders with new positive arc-drive control now prevent shorting when used on "drag" welding applications. In addition, they allow complete penetration on root passes of vertical and overhead welds. Arc-drive control is obtained by adjusting the ratio of short-circuit current to welding current without changing open-circuit voltage. Actual amount of arc-drive current can be varied by the operator.

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SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Stump the Experts

Baltimore, Md.—The May meeting of the *Maryland* Section held on the 16th was primarily a social meeting with the wives of members invited to be present. The dinner and meeting were held at the Engineers' Club of Baltimore. Three door prizes were awarded to lucky members selected by drawing names from a hat at the dinner. The prizes which were free dinner tickets were won by Charles Basel, Art Kluth, and Joseph Nicodemus, AWS members.

Following the dinner a motion picture, "Meet North Carolina" was shown through the courtesy of the Standard Oil Company of New Jersey. This movie took the audience on a tour through the state showing the beautiful scenery, points of interest and industrial occupations.

Instead of the usual technical session, a "Stump-the-Experts" session followed. The experts selected from the members of the Section were Fritz Albrecht, Glenn L. Martin Co.; A. L. Lees, Consolidated Gas Electric Light & Power Co.; L. H. Matthews, Guilford Welding Supply; and R. L. Sibley, Balmar Corp. Members in the audience were invited to ask technical questions of the experts. Gifts of miniatures or pen and pencils were given for questions asked and special prizes of cigarette lighters were awarded to those who stumped the experts with their questions. A great deal of interest and much discussion was aroused by the various questions which were submitted.

The newly elected officers and executive committee members were present at the meeting. The officers for the coming year are:

Chairman—A. L. Lees, Consolidated Gas Electric Light & Power Co.
Vice-Chairman—Harrison S. Sayre, Bureau of Ships.
Secretary—L. H. Matthews, Guilford Welding Supply.
Treasurer—J. Forsyth, Maryland Drydock Co.

Election of Officers

Chattanooga, Tenn.—The following officers and chairmen of committees have been elected by the *Chattanooga* Section for 1952–53:

Chairman—C. T. Ward, 2005 Chamberlain Ave., Chattanooga 4, Tenn.
First Vice-Chairman—J. W. Koch, 4317 Kemp Dr., Chattanooga, Tenn.
Secretary-Treasurer—Fain W. Ingram, City Boiler Inspector, City of Chattanooga, City Hall.
Chairman, Membership Committee—George L. Tepley, 1611 Knickerbocker, Chattanooga.
Technical Representative—R. E. Lorentz, 4604 Colonial Dr., Chattanooga.

High-Temperature Brazing

Chicago, Ill.—The regular monthly dinner meeting of the *Chicago* Section was held on April 18th at Burke's Grill & Restaurant with an attendance of 46 and 68 at the technical session. R. L. Peaslee, AWS, Wall Colmonoy Corp. was the speaker at the technical session. A brief abstract of his subject "Brazing for High-Temperature Service" is given herewith.

Many stainless steel designs were piling up on shelves begging for heat and corrosion-resistant brazing alloy to fabricate them. So a nickel-chromium-boron alloy was born and its ensuing development is beginning to play an important role in stainless fabrication.

To get to the brazing of this particular alloy and the equipment now employed, a specialized atmosphere controlled furnace is used because in it the processing cycle can offer maximum joint strength with minimum distortion. Since the stainless steel emerges bright and clean and flux is not required to facilitate the flow of the brazing alloy, this type of equipment proves most valuable. A metal retort is generally used with this furnace because the dew point requirement of below −40° F precludes the use of many standard furnace materials and designs.

Physical properties of joints brazed with this nickel-chromium-boron alloy show very good strength at room temperature and remarkable strength at elevated temperatures.

In the short time since a relatively low-temperature stainless brazing alloy has been available, its usage has been a boost to jet engine fabrication. Future advancement in this brazing field is expected to lead the way to widespread fabrication of brazed stainless parts and assemblies.

Mr. Peaslee graduated from Chemical Engineering Department, University of Cincinnati. In 1941 he became affiliated with The Materials Division of the Wright Aeronautical Corp. at the Cincinnati Plant. Upon the close of the Cincinnati Plant in 1945 Mr. Peaslee was transferred to the Main Plant of the Wright Aeronautical Corp. in New Jersey and did development work on welding and brazing of jet engine components. He joined the Wall Colmonoy Corp. in 1950.

A film entitled "Seagoing Thrills" was also shown and enjoyed by all.

Annual Welding Symposium

Cleveland, Ohio.—The 13th Annual Welding Symposium of the *Cleveland* Section, held on May 9th at Hotel Allerton, broke all previous attendance records. Dinner was served to over 500 guests. The Cleveland Section was happy that the area chapter of American Institute of Steel Construction made this symposium the occasion of its semiannual regular meeting.

Twenty-nine exhibitors participated in the educational exhibit. The exhibits of welding technique, procedures and know-how attracted much interest.

Three papers were presented at the afternoon technical sessions. The first paper was on the "Fundamentals of Resistance Welding" by Robert C. Glatz, Electrical and Welding Engineer of the Perfection Stove Co.

Mr. Glatz thoroughly covered the many factors in securing good resistance welds. A good weld results with the proper heat applied in the "squeeze" time, "weld" time, "hold" time sequence. The heat is determined by the I^2RT relationship where I is the current, R is the resistance and T is the weld time.

Current is controlled primarily by the good judgment of the operator in tap selection and is also affected by the R factor. R is affected by the surface condition (cleanliness) of the work and accuracy of welding tip contact with the work. Various methods are used in weld-time control.

Tip contact area maintenance is important for proper current, heating and pressure. Even though the proper tip, in good condition, is used, the pressure must still be adjusted to the requirements of the job. Insufficient pressure will result in burning while excess pressure will cause indentation.

The work must be designed for resistance welding. If possible, the design should be such that straight electrodes will do the job. Offset electrodes should only be used as a last resort.

In spot welding, the number of spots should be kept to a minimum. Spots made in too close proximity will be weak because of the shunting of weld current away from the weld area.

Mr. Glatz gave many practical pointers in keeping costs down in a resistance-welding department. Water cooling to within $\frac{1}{2}$-in. of the tip will assure long electrode life. Design for straight tips will also result in better and lower cost welds and will make alignment easier. A drop of oil on the taper when an electrode is installed will facilitate its easy removal.

N. C. Jessen, Metallurgical and Welding Engineer of Babcock & Wilcox Co., presented the second conference paper on "Weldability of Low-Alloy and Austenitic Stainless Steels."

Mr. Jessen's talk stressed the metallurgical and welding factors in the joining of these metals. Many slides were used to illustrate the great variations in tensile strength resulting from various techniques. He suggested a preheat of 600 to 700° to control hydrogen from the coatings of rim steel electrodes.

Mr. Jessen discussed the welding defects resulting from the use of improper electrodes. His paper included gas welding, atomic hydrogen welding and arc

welding in the welding of chrome-moly steels. Comparison of as-welded and heat-treated welds of these steels were made to show mechanical properties and the micrograph structures.

The second part of the paper was devoted to a discussion of welding techniques and electrodes to get good stainless steel welds. The discussion also included the type of weld imperfections from improper techniques or electrodes.

The third and last paper was presented by LaMotte Grover, Structural Welding Engineer, Air Reduction Sales Co., on "Practical Design and Control for Welded Structures."

Mr. Grover discussed details of design, method of construction, welding procedure and control for welded fabrication of the structural components of buildings and bridges. He also spoke of building code provisions.

A large number of slides illustrated welded design features of both buildings and bridges. Many of the more recent buildings erected in Houston, Fort Worth and Dallas, Tex., furnished excellent examples for welded connections of beams to columns.

Mr. Grover discussed the use of 2- and 3-bolting and drift pin aligning holes where welds were made. Engineering of designs has reduced the weld metal from an amount exceeding 14 lb to the ton of structural steel to 4 lb per ton of steel.

The Republic Structural Iron Works Co. exhibited a typical section illustrative of the structural fabrication described by Mr. Grover in one of the Houston buildings. This section was an internal floor section with four beams jointed to a column, each beam 90 deg from its two adjacent beams.

This exhibit was fabricated from actual structural components and illustrated the method of steel erecting using three holes for drift pin aligning and bolting the main members before field welding. All welds on the exhibit were clearly labeled indicating those that are to be shop welded and those that are to be field welded.

Mr. Grover concluded his paper with the example (illustrated by progress slides) of the complete rebuilding of a New England department store. A small portion of the store was demolished and rebuilt while business continued in the remaining original portion of the building. After completion of the first construction the process was repeated on a second portion with business being done in the completed new portion and the remaining old part of the store. This procedure was followed until the entire store was completely rebuilt with no interruption or curtailment of the store's normal business during the rebuilding.

This was made possible by the use of all-welded steel construction since the entire operation was quiet. Although no figures were given, it seems reasonable that public interest during the rebuilding period could very well have increased the volume of the store's sales.

Following the banquet, A. G. Hopcraft, Director of Purchases for Cleveland Worm & Gear Co. and Farval Corp., took over as toastmaster. Mr. Hopcraft, after the routine introductions of the VIP's comprising the wax works, introduced the main evening speaker, Dr. Ralph L. Lee, member of the Public Relations Department of General Motors Corp.

Dr. Lee spoke on the subject "Man to Man on the Job." The talk dealt with the idiosyncracies of individuals. The talk was "down to earth" in the humorous presentation of the various types: the thinker, the ants-in-the-pantser, the prevaricator, the down-in-the-mouther, the bulldozer, the joker, the self promoter, the piddler, the egotist, etc. As a discourse in human relations—it was tops.

The afternoon technical sessions were held in the Mather Room and it was noted that there were very few vacant chairs in the room whose capacity is about 300. The Cleveland Section was happy to have many visitors from neighboring sections and was especially pleased that AWS national secretary, J. G. Magrath, was one of many distinguished visitors.

The Cleveland Section of the AMERICAN WELDING SOCIETY was organized in 1921 and is, today, the second largest section of the SOCIETY. Past-chairmen of the Section include J. C. Lincoln, President, Lincoln Electric Co.; F. L. Plummer, Design Engineer of Cleveland's Main Avenue Lake Shore Freeway Bridge; M. M. Boylston, formerly Professor of Metallurgy of Case Institute of Technology; K. C. Thornton, Naval Architect of American Ship Building Co.; and A. E. Gibson, President of Wellman Engineering Co. and Past-President of the AMERICAN WELDING SOCIETY.

Section officers whose terms are expiring are Chairman J. B. Austin, Welding Engineer, Republic Welding and Flame Cutting Co.; First Vice-Chairman Frank Flocke, Engineer, The Thornton Co.; Second Vice-Chairman R. J. Henry, Welding Engineer, Cleveland Diesel Division of General Motors Corp.; Secretary-Treasurer, J. F. Wagner, Vice-President, Burdett Oxygen Co. Incoming Section Officers are Chairman Frank Flocke; First Vice-Chairman Lewis Gilbert, Editor, *Industry and Welding;* Second Vice-Chairman R. J. Henry; Secretary-Treasurer J. F. Wagner.

The annual Cleveland Section Symposium developed largely from a realization of the value of welding to the country in the industrial production for war. J. F. Maine Chief Engineer, Republic Structural Iron Works, went to work on this idea in 1939 and the first conference was held at Hotel Statler on May 3, 1940, with an attendance of about 300 engineers.

It is with sadness that we report the death of Percy Crittenden of Elyria, Ohio, who was with the American Ship Building Co. at the Lorain, Ohio, ship yards.

Mr. Crittenden was Cleveland Sections member of AWS for many years and had many friends in the Section. He was stricken in the midst of his friends at the symposium banquet. The police and fire department rescue squad administered first aid but failed to revive Mr. Crittenden.

Temperature Control

Dallas, Tex.—Arthur Tesmen, AWS, Tempil® Corp., New York, was the guest speaker at the April 23rd meeting of the *Dallas* Section held at the Mosher Steel Co.'s recreation room. Mr. Tesmen presented an excellent extemporaneous talk on "Control of Heat Treatment Temperatures."

Inspection Tour

Dallas, Tex.—An inspection tour of the Wyatt Metal & Boiler Works facilities and processes was held on May 21st with an attendance of 38. This was also the annual meeting of the *Dallas* Section.

Demonstrations

Dayton, Ohio—The *Dayton* Section had an excellent turnout to the May meeting held on the 6th at the Hobart Trade School at Troy, Ohio. Robert Berceaw, AWS, chief instructor, was host for the evening. Before the demonstrations started Mr. Berceaw gave a short talk on training welders and the work being done by the Hobart Trade School. Also present was Clyde Whitmire, welding specialist on pipe-line construction who gave a short talk on welding in the oil fields.

Mr. Berceaw introduced his helpers—five instructors from the school who aided in the demonstrations.

There were simultaneous demonstrations on gas welding and cutting, manual welding with consumable electrodes, inert-arc welding with tungsten electrode and filler rod, semiautomatic welding using the sigma weld, fully automatic welding using exposed arc and submerged arc, and special applications in stud welding, metal spray and X-ray of welds. This variety of equipment gave the section a good perspective on current welding practices using gas and electric.

Before the meeting, the membership was invited to have dinner and informally talk over the business of the Section with the local executive committee. Dinner was held at the Camp Troy Restaurant in Troy, with an attendance of 30 at dinner and sixty-five at the demonstrations.

Dayton Section May Meeting

Positioning

Denver, Colo.—Forty-six members and guests were present at the dinner meeting of the *Colorado* Section held on May 15th at the Shirley Savoy Hotel in Denver. Coffee speaker was Verne Schroer, AWS, of the General Iron Works. Mr. Schroer explained the duties of the technical chairman.

Speaker at the technical meeting was Anthony Pandjiris, AWS, of the Pandjiris Weldment Co. whose illustrated subject was "Set the Pace, Win the Race." He discussed the advantages of positioning the work, positioning the man and positioning automatic and semiautomatic welding heads.

Plant Tour

Fort Wayne, Ind.—Members of the *Anthony Wayne* Section went by automobile to Lima, Ohio, on May 16th and made a plant tour of the Baldwin-Lima-Hamilton Corp. The members went through the entire plant which covered a great many acres starting at the plate preparation, fabrication departments and then the machine shops and assembly lines. They saw the latest design in army tank hulls—one-piece armor plate assemblies, the gigantic machines used for various machining operations and the many welding operations for transforming the rough cast hull into a finished precision unit. They also saw the production line of navy amphibious tanks. These were all-welded units of which the industry could be justly proud. They also saw X-ray equipment and the other testing apparatus used for inspecting finished welds. It was a very good setup and the company's guides were very courteous during the entire trip.

After seeing the tanks, they went through the buildings where power shovels, cranes and rock crushers are built. A number of jobs were set up on automatic submerged arc welding which were interesting to everyone. The company has a well-planned shop and very good equipment with heavy cranes to do the handling. The members and guests were all pleased with the tour and the manner in which their guides showed them through the plant. Fifty-two attended the banquet at the Sarnos Restaurant and 110 made the tour.

Symposium—Welded Structures

Houston, Tex.—A symposium on welded steel plates was held by the *Houston* Section on Thursday, May 15th, in the Cullen Auditorium, University of Houston Campus, with a turnout of about 200. The program consisted of the following speakers and subjects:

"Welded Steel Buildings—Designing and Engineering"; Speaker—Boyd Meyer who is associated with Robert J. Cummins, consulting engineers. Mr. Meyer is among the pioneers in the design of welded steel buildings, having designed some of the largest and latest buildings erected in Houston.

"Welded Steel Buildings—Shop Fabrication"; Speaker—H. F. Crick, AWS, Welding Supervisor, Mosher Steel Co. The Mosher Steel Co. has fabricated most of the large office buildings that have been erected in this area, and have been furnishing structural steel to the trade since 1885.

"Welded Steel Buildings—Field Erection"; Speaker — Homer Peterson, Partner, Peterson Bros. Steel Erection Co. Peterson Bros. have erected most of the welded steel buildings that are now standing in the city of Houston.

"Welded Steel Buildings—Shop and Field Inspection"; Speaker—W. H. Greer, AWS, Assistant Manager, Southwestern Laboratories. Southwestern Laboratories have for more than 25 years been active in the inspection of construction projects of all types. Their experience with welded structures qualified them, through Mr. Greer, to present this subject.

Papers were presented by each of the speakers on their subject, after which a short recess was taken to allow written questions to be presented for the panel to discuss immediately following the recess. The entire program was recorded and will be edited and published. Included in the publication will be the papers presented and the questions and answers of the discussion period. This publication is being made available for $3.00 each to cover costs.

Election of Officers

Indianapolis, Ind.—Officers for the

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1952–53 season of the *Indiana* Section are as follows:

Chairman—Alexander B. Pollock.
First Vice-Chairman—Robert L. Evans.
Second Vice-Chairman—James L. Salatin.
Treasurer—Paul F. Grubbs.
Secretary—Mercedes Spotts.

Quiz the Experts

Indianapolis, Ind.—A "Quiz the Experts" followed a buffet dinner and short business session at the April meeting of the *Indiana* Section held on the 25th at the Hotel Antlers, this city. The contest was lively, entertaining and the competition close. The questions covered the metal joining field in general and the quiz teams came through with the answers. There was something of interest for everyone present. Ray Wirt, AWS, served as moderator. James F. Salatin, William G. Morgan and E. E. Goehringer, AWS members, were judges. Three teams competed as follows: The Detroit Team consisting of Roy Clark, AWS, Patrick S. Doyen, AWS, J. E. Rainey, AWS, and Ivon O. Shepard; the Michiana Section consisting of George Fetherston, George Mittler, Lloyd Ebert, and Erwin Laylin, AWS members; and the Anthony Wayne Section consisting of George Laws, Harold Hamilton, D. B. Rice, and Virgil Beck, AWS members. The Detroit Team won the contest by a close margin and took the trophy home.

Sixty-eight members and guests took part in the quiz program and were also present at the predinner get-to-together held in the Coral Room.

Weldment Positioning

Kansas City, Mo.—Anthony Pandjiris, AWS, President of the Pandjiris Weldment Co., St. Louis, Mo., gave an excellent talk entitled "Set the Pace, Win the Race" at the May 13th dinner meeting of the *Kansas City* Section held in the Benish Restaurant. Twenty-two members were present at the dinner, and 28 at the meeting that followed.

Mr. Pandjiris discussed the advantages of positioning the work, positioning the man and positioning automatic and semiautomatic welding heads. His remarks were accompanied by slides.

Mr. Pandjiris is very active in the AWS. He is Past-Chairman of the St. Louis Section and is a member of the National Nominating Committee for 1951–52. He was one of the two Missouri winners of the Lincoln Foundation Award on design for better welding.

The Kansas City Section will be host for the District 6 meeting to be held on July 19th. Representatives of the Houston, Dallas, Denver, Wichita, Oklahoma City, St. Louis and Tulsa Sections will attend. All members are invited to attend this District meeting.

Officers and directors for the 1952–53 season were announced as follows:

Chairman—J. M. Payne, Butler Manufacturing Co., Kansas City.
Vice-Chairman—A. G. Hedstrom, Kansas City Structural Steel, Kansas City.
Secretary—D. E. Broderson, Butler Manufacturing Co., Kansas City.
Treasurer—E. M. Hotchkiss, 1534 S. Ash, Independence, Mo.
Attendance Chairman—A. H. Browning, 4121 College Ave., Kansas City.
Program Chairman—G. G. Demecs, Westinghouse Electric Corp., Kansas City.
Membership Chairman—J. E. Dato, Linde Air Products Co., Kansas City.
Directors—P. D. Blake, L. L. Cramer, D. E. McCormick, D. Burrows, J. L. Hollandsworth, A. C. Sluss, and M. L. Powers.

Outline of Welding

Long Beach, Calif.—F. G. Harkins, AWS, Solar Aircraft Co. presented an excellent address on "Outline of Welding and Machinability" at the May 16th dinner meeting of the *Long Beach* Section held at Millers Restaurant. Mr. Harkins' talk covered the methods of welding and was of interest to engineer and operator. Slides were also used.

The Long Beach Section announces the election of officers and chairmen of committees for 1952–53 as follows:

Chairman—A. H. Butler, 1024 D. East San Antonio Dr., Long Beach 7, Calif.
First Vice-Chairman—C. L. Breese John Tillman & Co.
Recording Secretary—P. E. Anderson, H. I. Tullis.
Secretary-Treasurer—O. B. Bowers, Bowers Ambulance Service.
Chairman, Membership Committee—W. A. Williams, 3070 Chestnut Ave.
Chairman, Program Committee—C. L. Breese.

Welding Stainless and Alloy Steels

Los Angeles, Calif.—James E. Norcross, AWS, Sales Manager of Arcos Corp., Philadelphia, Pa., addressed the *Los Angeles* Section at their May 15th dinner meeting held at Swally's Cafe on the subject of "Unusual Problems Encountered in Welding Stainless and Alloy Steels and Their Proposed Solutions."

Mr. Norcross stressed that differential expansion accentuates failure in many cases. The weld deposit should match the composition of the plate, as nearly as possible, in chemistry. But plate is wrought, while weld metal is cast. There is a difference in the physical properties. Root cracks tend to propogate through the entire weld. Ferrite in the weld metal is a crack inhibitor. Martensite is very hard and tends to form cracks. Austenite in the weld metal is ductile and does not change with heat treatment. The aim should be to avoid the formation of martensite, as far as possible. He cited a number of examples where trouble had occurred and told how thorough investigation, backed by laboratory tests, had solved the problems. In the AISI Type 308, 18/8 chrome-nickel group, he used as an example Type 304 stainless beer barrels which had been welded by the atomic hydrogen process. These barrels were badly attacked in the fusion zone during the pickling operation. Investigation proved that the parent metal was low in chromium and low in silicon. The low silicon probably resulted from insufficient deoxidization of the melt at the mill. The low silicon contributed to the lowering of the corrosion resistance. The parent metal simply did not conform to the requirements of this group.

Sugar kettles were cited as another example of troubles that can occur with the 308 group. The weld metal and parent metal were found, as were the physical properties, to be okay. But investigation

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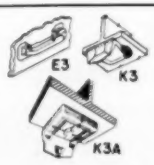

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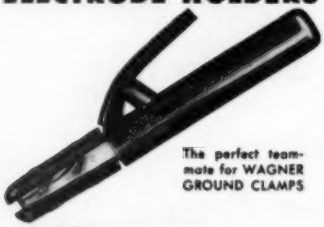

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Weld with Wagner

showed that ferrite can be preferentially attacked. An X-ray diffraction disclosed food particles in the weld. The trouble was remedied by welding the seam with Type 308 rod, overlaying the parent metal with Type 347 each side of the weld, and then depositing Type 316 over all.

The speaker stressed that austenite can be converted to ferrite by cold work. Stainless wire brushes are an example. They become magnetic after a short period of work which indicates that carbide precipitation is not always the offender.

In the 9% chrome-molybdenum group, Mr. Norcross used as an example pipe handling a liquid. The pipe joints were welded with 25/20 rod. Investigation showed that the welding closely approached a completely homogeneous structure. The work was preheated and postheated in the best practice for 9% chrome material. But the pipe sweated around the welds. Failure was due to minute fissures. They could not be detected by magnification, X-ray or dye-penetrant. After resorting to a bend test, small cracks or intergranular fissures were found. These fissures originated in the root bead. This points up the fact that a 25/20 deposit may be susceptible to cracking. If the carbon, silicon, phosphorus and sulfur in the weld rod are carefully controlled, the trouble can be eliminated. A lime coating on the rod helps because it tends to purify the weld metal. Heat treatment is not recommended for this combination of metals.

In regard to the 347 group, the speaker was of the opinion that here is a bad actor as a weld metal. And he pointed out that we should not use columbium-bearing rod unless it is really necessary, even if we can obtain it. Trouble may result from what seems to be a good precautionary choice of weld rod. He used coke by-product vessels as an example. The original vessels were rubber-lined. As strategic materials became available, after World War II, the owners decided to jump to stainless for replacement vessels. Type 304 would have been satisfactory but someone suggested Type 347. So, 347 it was. After only three months' service, the vessels developed service corrosion in the weld metal. The corrosive media were ammonium sulfate and sulfuric acid. Type 316 stainless is generally used for acid service.

In this case, carbide precipitation was not the offender. There was no plate decay in the heat-affected zone. The Type 347 deposit was partly ferritic and was attacked by the acid. As a solution for the problem, all weld metal could have been removed and the joint then be rewelded. Actually, the problem was solved by putting on a cover pass of columbium-stabilized 25/20.

He cited an example of trouble with Type 347 in the case of weld metal cracking on heavy sections. The welds were sound after deposition, but they cracked after heat treatment at 1700° F. There was no control on the rate of cooling. During the sigma transformation under restraint of the heavy sections, the welds cracked during the heating cycle. After making up several electrode compositions and welding samples under restraint, it was found that a ferrite content of at least 3% is required. Another example of similar trouble concerned the welding of heavy nozzles in heavy-walled vessels. The problem was solved by segmenting portions of the vessel shell around the nozzles. The segments were first welded to the nozzle, then the radial seams were welded, then the round seam.

In the Type 316 group, some sodium hydride descaling racks offered a good example. After alternate heating and exposure to sodium hydride and water, stress-corrosion cracks were found. After refabricating the racks and heat treating them, they were found to be satisfactory. Carbide precipitation was the offender in this case.

Mr. Norcross, a graduate of MIT, has been instrumental in the development of many of the electrodes and his company has followed through on the application of those electrodes to various welding processes and materials. As a result of the broad experience developed through actual case histories of many fabrication and corrosion problems, he has accumulated many valuable and interesting data, from which he extracted the subject matter of his talk.

The members of the Los Angeles Section found Mr. Norcross' talk to be very interesting and instructive. They appreciate his efforts in making a trip to the west-coast to talk to their group. Ninety members of the Section were present at dinner and 95 at the technical meeting which followed.

Preheating for Welding

Louisville, Ky.—Arthur B. Tesmen, AWS, Tempil® Corp., New York, was the speaker at the May 27th dinner meeting of the *Louisville* Section. Mr. Tesmen gave an interesting talk on "Preheating for Welding." He covered the problem of weld cracking and distortion by using the iron carbon diagram and did it in such a manner that the uninitiated could thoroughly understand the subject. His discussion indicated that preheating would eliminate the majority of weld cracks.

Annual Get-Together

Milwaukee, Wis.—The *Milwaukee* Section held its Fifteenth Annual informal get-together on Saturday, May 24th in the Sky Room, Plankinton Hotel, with 196 attending.

An excellent dinner was served followed by installation of officers with entertainment and dancing afterward. The newly elected officers are as follows:

Chairman—F. E. Garriott, 2336 S. 57th St., West Allis 14, Wis.
First Vice-Chairman—W. Gallo, 616 N. 112th St., Milwaukee 13, Wis.
Secretary-Treasurer—F. J. Harencki, 4508 S. Lawlor Ave., Cudahy, Wis.

This concludes the activities of the Milwaukee Section for the season.

Radiography

Newark, N. J.—Harold Havoland, President of the Industrial X-Ray Engineers, Seattle, Wash., at the meeting of the *New Jersey* Section held on May 20th, presented a very interesting story covering the experiences of the X-Ray Engineers Co. leading to the development of a portable self-powered X-ray machine for radiographic inspection of welded transcontinental pipe lines. The described unit operates within the pipe and exposes the complete circumferential weld in one operation. Mr. Havoland pointed out that a controlled spot-check system has proved to be an adequate quality control measure for pipe-line applications.

A very excellent and interesting sound motion picture describing the construction of the largest welded pipe line in Canada supplemented Mr. Havoland's talk. Of particular interest were the details of the portable X-ray equipment used by the X-Ray Engineers on this job and the constructional details showing how welded sections of the pipe line crossed wide rivers. This pipe line was constructed from the Edmonton Oil Basin to Duluth, Minn., by Imperial Oil Limited.

The dinner and meeting were held at the Essex House with an attendance of 30 at dinner and 70 at the meeting.

After-meeting refreshments and social hour followed.

Election of Officers

New York, N. Y.—The newly elected officers for 1952–53 of the *New York* Section are as follows:

Chairman—H. R. Clauser, Materials & Methods.
First Vice-Chairman—S. T. Walter, Air Reduction Sales Co.
Second Vice-Chairman—W. E. G. Lucas, 205–24 116th Ave., St. Albans 11, N. Y.
Secretary-Treasurer—E. W. Axthelm, Linde Air Products Co.

Fabrication Plant Tour

Oklahoma City, Okla.—The April 22nd meeting of the *Oklahoma City* Section attended by 45 members and guests consisted of a tour of the plant of Black, Sivalls and Bryson. This is one of the most modern heavy fabrication plants in the Southwest having recently doubled its production area by the addition of a new section 80 ft wide by 600 ft long. This section is served by 50- and 25-ton cranes.

Other recently added production facilities include a stress-relieving furnace 13.5 ft wide by 15 ft high by 80 ft long, and forming rolls with a capacity for forming plate 3 in. thick by 10 ft wide.

Following the plant tour, Howard Simms, AWS, presided over an interesting question-and-answer session held at the Jack Barnes Club Room. The meeting was concluded with refreshments.

Marine Corrosion Control

Pascagoula, Miss.—Frederick King, Jr., Field Engineer for the Metallizing Engineering Co., delivered a paper on "Marine Corrosion Control by Metallizing" at the May 7th monthly dinner meeting of the *Pascagoula* Section held at the Ingalls Cafeteria. Fifty-two were present from five coastal cities representing eight industries. Mr. King's excellent paper was well illustrated with a number of slides. The paper was semitechnical and covered new applications and processes. Alton Mansfield, AWS, Chairman, presided at the meeting.

Thomas J. Dawson, AWS, Metallurgist, Ingalls Shipbuilding Corp., introduced the coffee speaker of the evening, M. B. Lanier President of the Ingalls Shipbuilding Corp. who was introduced to the group as a new sustaining member representing the Ingalls Shipbuilding Corp., Pascagoula, Miss.

Submerged Arc Welding

Peoria, Ill.—Harold A. Baldwin, AWS, Welding Engineer of R. G. LeTourneau, Inc., Peoria, gave a talk on "Application and Savings with Manual Submerged Arc Welding" at the April 16th dinner meeting of the *Peoria* Section held at the Sazarac Restaurant. Mr. Baldwin's talk was accompanied by slides showing the various applications his company has successfully used.

Mr. Baldwin pointed out various jobs where they were making substantial savings by changing from manual arc to submerged welding. He listed various jobs where welding and cleaning time was greatly decreased. He said very little weld splatter would be found on submerged-welded parts as the flux would catch and hold most of it. He stated they were having success in welding steel with a rather high carbon content without preheat or postheat. Carbon on some jobs runs as high as 0.62% and failure in this field has been greatly reduced by using this process.

The members and guests displayed great interest in Mr. Baldwin's talk and asked numerous questions.

Eighty-one members and guests enjoyed a chicken dinner and 83 people were present for the meeting.

Election of Officers

Peoria, Ill.—At the annual business meeting of the *Peoria* Section held on May 21st at the Sazarac Restaurant the following officers were elected for 1952–53:

Chairman—D. L. Stine.
Vice-Chairman—G. A. Deemy.
Treasurer—J. L. Hanley.
Secretary—L. W. O'Day.
Executive Committee—Mort Packer, Cliff Wimmer, Dean Batton, John Brown, Joe Ricca and Russel Bahr.

Through the courtesy of the Marquette Manufacturing Co. of Minneapolis a 16-mm. sound color film entitled "Marquette Goes to the Races" was shown during the meeting.

Election of Officers

Philadelphia, Pa.—The newly elected officers for the Philadelphia Section are as follows:

Chairman—R. A. Guenzel, Southern Oxygen Co., Philadelphia, Pa.
First Vice-Chairman—R. D. Bradway, New York Shipbuilding Corp., Camden, N. J.
Recording Secretary—H. A. Young, K. W. Ostrom and Co.
Secretary—R. David Thomas, Jr., Arcos Corp.
Treasurer—A. M. Garcia, Morris Wheeler & Co.

Choosing the Right Electrode

Phoenix, Ariz.—On Wednesday, May 21st, the *Arizona* Section held its monthly meeting in the Saratoga Room of the Westward Ho Hotel.

The speaker of the evening was William F. Fischer, AWS, Welding Engineer, of the Lincoln Electric Co. who spoke on "Choosing the Right Electrode for the Job." Mr. Fischer's presentation was unusually interesting as he not only gave the technical reasons for the use of different electrodes but gave practical experience illustrations to substantiate them. For instance, in discussing the new low-hydrogen electrodes he pointed out that in the former days bare rods were often the only successful means of welding different steels thus proving the beneficial effect of elimination of hydrogen.

Very graphic examples of the reduction of costs using automatic and semiautomatic welding machines were brought to the Section's attention by Mr. Fischer.

Following the speaker's talk, a technicolor sound film, "Oil Across Arabia," was shown by Morris Aspey, AWS, Plant Manager of the local Consolidated Western Steel Division of U. S. Steel, through the courtesy of the Bechtel Corp. The problems in this project were many and were interestingly solved as shown by the film.

All present agreed the meeting was very successful and heartily thanked those responsible for it.

Inert-Gas Welding

Portland, Ore.—It was the unanimous opinion of the membership of the *Portland* Section that the May 21st dinner meeting with an attendance of 55, was the best held so far this year.

The speaker, J. Warden Cunningham, AWS, Air Reduction Sales Co., New York, spoke on the subject "Latest Developments on Inert-Gas Welding" with particular reference to recent jobs done on stainless copper and bronze. Interesting slides were also furnished which Mr. Cunningham commented on in connection with his talk.

A Social Evening

Rochester, N. Y.—The *Rochester* Section held its last meeting before the summer recess at the Rochester Turners Club on May 19th. A capacity crowd turned out to make it a huge success. A delicious dinner in the form of a smörgåsbord was served at 7:00 P.M. with refreshments available throughout the evening. Immediately following the dinner, a tumbling act was presented by the Rochester Turners Club by the younger generation, ranging from six to twelve years of age. Many of the acts brought back memories of younger days.

The 1952–53 officers were installed with Bill Connley acting as Master of Ceremonies. They are as follows:

Chairman—Gomer Stelljes, W. C. Sykes Co.
Vice-Chairman—Clyde Martin, William J. Meyer Co.
Secretary-Treasurer—Walter Dick, Eastman Kodak Co.
Executive Committee—Ted Milatz, Eastman Kodak Co.; Nelson Martin, Foster Wheeler Corp.; Robert Boss, All-State Welding Alloys; Robert Barr, Rochester Steel Treating; William Weber, A. O. Smith Co.; Richard Abery, Pfaudler Co.; and William Meyer, Wm. J. Meyer Co.

Harry Stoler, Past-Chairman, congratulated the past officers for their excellent support and wished the new officers success. The remainder of the evening was spent bowling, playing cards and singing, with the aid of refreshments.

It was announced that the Foster Wheeler Corp., Dansville, N. Y., has extended an invitation to hold the first fall meeting at their plant in the form of a plant visitation.

The Importance of Welding

Saginaw, Mich.—T. B. Jefferson, AWS, Editor of *Welding Engineer*, gave an ex-

cellent presentation on "The Importance of Welding in Our Everyday Lives" at the April 10th dinner meeting of the *Saginaw Valley* Section held at Zehnder's Hotel, Frankenmuth, Mich. Sixty-seven members and guests were present at the dinner and meeting.

A colored travelog of pictures taken by Jim Alcock, AWS, on his trip to Puerto Rico and the Virgin Islands was thoroughly enjoyed.

Ladies Night

Saginaw, Mich.—The *Saginaw Valley* Section had a Ladies Night on May 14th with a buffet-style dinner at the Rolling Greens Country Club in Saginaw. An attendance of 55 thoroughly enjoyed the dining, dancing and door prizes.

Old Timer's Night

San Francisco, Calif.—In honor of their many fine past-chairmen, the *San Francisco* Section had an Old Timer's Night on Monday, May 26th at the Engineers Club. The San Francisco Section is celebrating its 30th anniversary this year. Following a delicious baked ham dinner a number of past-chairmen were introduced and gave very interesting talks. These were H. L. Wintersgill (1922–23), G. O. Wilson (1925–26), Frank Longo (1942–43), Mark Haines (1946–47) and R. E. Labagh (1950–51).

William F. Ajello of the Dependable Welding Service was presented his past-chairman's engraved AWS pin by First Past-Chairman R. E. Labagh.

Also heard from were several long-time members, among whom were G. L. Hammon, Vice-President and General Manager of National Welding Equipment Co., and E. H. Croft of Oliver Filter Co.

It was a wonderful and enjoyable gathering of 44 members.

Ladies Night and Election of Officers

Schenectady, N. Y.—Ivar W. Johnson was elected Chairman of the *Northern New York* Section during a recent meeting at Dinty's Terrace Gardens, Latham, N. Y., Mr. Johnson, employed in the Resistance Welding Section of the Schenectady Works Laboratory of the General Electric Co., has been Secretary-Treasurer for the past three years and succeeds Westley J. Van Nattan, who was elected to the Board of Directors with Henry J. Peters of the Eutectic Alloys Co.

Other officers elected are C. R. Molenaar, Industry Control Department, General Electric Co., First Vice-Chairman, Dr. E. Nippes, Professor at RPI, Troy, N. Y., Second Vice-Chairman, and R. M. Rood, General Electric Co., Pittsfield, Mass., Secretary-Treasurer.

This was Ladies Night Meeting and consisted of a dinner followed by dancing and entertainment.

Election of Officers

Seattle, Wash.—The newly elected officers for the *Puget Sound* Section are as follows:

Chairman—Robert C. Hermon, 3006 Walnut Ave., Seattle 6, Wash.
First Vice-Chairman—L. M. Crawford, 508 Summit Ave., N., Seattle
Secretary-Treasurer—Don W. Axworthy 7127 28th Ave., S. W., Seattle.

Metal Spray

South Bend, Ind.—On April 17th, the *Michiana* Section wound up its technical series with a talk and demonstration of metal spraying put on by Robert Brady, AWS, District Manager, Metallizing Engineering Co. Prior to setting up the apparatus, Mr. Brady discussed the process, its possibilities and limitations.

Metallizing, as the process is known, is not a panacea and when used in the proper place, still needs to be properly done if satisfactory results are to be obtained. Proper surface preparation and cleanliness are of utmost importance. Preparation by rough threading, fuse-bonding or spray-bonding, the latter a recent development utilizing a high-molybdenum alloy, can be used but each has its place. Mr. Brady, emphasized the use of the Molybdenum alloy, not only as a base for other metals, but as a sprayed coating on its own. It is especially desirable as buildup material in bearing areas. In fact, some plants are spraying new spindles because of the increased wear and decreased chatter obtained, primarily due to the hardness and lubricating properties of the coating.

After the demonstration, the audience had a much better appreciation of the process and how it is done. The Michiana Section thanks the Wheeler and Hamilton Welding and Machine Shop for letting them use their facilities for the meeting.

Northern New York (Schenectady) Section Ladies Night Meeting

Election of Officers

South Bend, Ind.—The *Michiana* Section finished its 1951–52 series with a business and social meeting on May 15th. A review of the past season was followed by election of officers. The following men will lead the section next year:

Chairman—George Fetherston.
Vice-Chairman—Erwin Laylin.
Secretary—W. G. Fassnacht.
Treasurer—J. A. Miller.
Executive Committee—Henry Wheeler, H. E. Kellogg, Robert Phelps, James Hosterman, John Weis and Thomas Wilhelm.

With the serious part out of the way, an evening of fun began. Refreshments were served and a number of door prizes distributed by means of a series of bingo games.

Election of Officers

Springfield, Mass.—The newly elected officers for the *Western Massachusetts* Section are as follows:

Chairman—Victor L. Bissonnette, 201 Pasco Rd., Indian Orchard, Mass.
First Vice-Chairman—K. W. Braunschweig, Braun's Welding Service, West Springfield, Mass.
Secretary—George R. Pepin, Crescent Welders' Supply Co., West Springfield.
Treasurer—John J. Karabowski, 350 Main St., Three Rivers, Mass.
Chairman, Membership Committee—John De Marco, 94 Massachusetts Ave., Springfield, Mass.
Chairman, Program Committee—George Pepin and Norman H. Randall, 89 Lehigh St., Springfield, Mass.
Technical Representative—Carl Keyser, 75 Memorial Dr., Amherst, Mass.

Weld Design

Tulsa, Okla.—R. G. Todd, AWS, Welding Engineer for the Lincoln Electric Co., discussed some of the practical aspects of weld design at the March 15th meeting of the *Tulsa* Section. Mr. Todd presented some down-to-earth ideas on how to lower costs and improve quality through better use of welding in the production of machinery. He used some informative charts and interesting demonstrations to show comparisons between cast iron and steel, pointing out that we automatically have an initial cost advantage of seven to one in designing machinery for welded steel rather than cast-iron construction.

The talk was followed by a film on "Distortion" and a discussion period led by Mr. Todd. This program was in line with the Section's plan this year to use local talent as speakers and present subjects of more local interest.

Oil Drilling Industry

Wichita, Kan.—A talk of great interest to many of those in the area was given by Allen E. Wisler, AWS, Welding Engineer, Hughes Tool Co., Houston, Tex., at the

May 12th dinner meeting of the *Wichita* Section held in the Coleman Co., North Plant Cafeteria. Mr. Wisler's talk on "Welding in the Oil Drilling Industry" was accompanied by slides showing some of the techniques in welding and heat treatment of high-strength alloy tools.

Mr. Wisler was born and reared in Kansas and received his B.S. degree in chemistry in 1935 at the University of Arkansas. He has been connected with the Hughes Tool Co. since 1935. He is a member of AWS, ASM, Houston Engineering Club and Texas Society for Professional Engineers. Mr. Wisler is AWS Vice-Chairman for District 6 and has been very active in the affairs of the SOCIETY.

An added feature of the meeting was a plant tour of the American Steel Works where the operation of a large asphalt heating kettle was witnessed.

Officers of the Wichita Section elected for the coming year are as follows:

Chairman—Harry Moberly.
First Vice-Chairman—Orval W. Daniels.
Second Vice-Chairman—Bill Bush.
Secretary—Francis Hein.
Treasurer—Roy Whitt.

LIST OF NEW MEMBERS

Effective May 1, 1952

BIRMINGHAM

Shannon, R. F. (B)

BOSTON

Bacon, Lewis H., III (B)
Buckley, Robert L. (B)
Di Pronio, Carmine, Jr. (C)
Edvardson, Sigvard (B)
Flynn, Richard (B)
Hochhalter, A. R. (B)
Muzzey, C. L. (B)
Persson, Einar (B)
Putnam, Roy F. (B)
Rehbock, A. F. (C)
Talabach, Theodore (B)
White, Charles (B)

BRIDGEPORT

Peterson, Rolf Y. (B)

CHICAGO

Knibbs, Fred H. (C)
Miller, William D. (B)

CINCINNATI

Reckman, Albert C. (B)
Williams, Robert A. (B)

CLEVELAND

Clarke, Herbert (B)
Craven, Delbert Dewey (B)
Craven, Omer O. (B)
Hydock, John (B)
Kuhns, William (D)
McCracken, Robert H. (C)
McReady, Ross B. (B)
Mitchell, Howard H. (C)
Read, Thomas F. (B)
Stanley, Joseph R. (C)
Stuckey, Raymond R. (B)
Tucker, Paul K. (C)

COLORADO

Newman, Charles E. (C)
Ranum, Willard (B)
Ray, Carl J. (B)

COLUMBUS

Allen, Charles T. (C)
Lindemann, Ward E. (C)
Riegle, Robert L. (C)

DAYTON

Bennett, Mel (B)
Heller, Steven (C)

DETROIT

Brown, I. C. (B)
Burgess, James R. (B)
Davis, Joe (B)
Friend, J. Don (B)
Norberg, Ralph V. (D)
Reese, Joseph (C)
Ross, Henry T. (B)
Schroeder, Harold I. (C)
Smith, Carl T. (C)
Tickhill, Roland G. (B)
Welther, Robert S. (D)

HOUSTON

Ackerman, W. E. (B)
Bradford, W. G., Jr. (C)
Dennis, E. R. (C)
Franks, Fred E. (B)
Jacobson, John E. (B)
Kronenberger, L. R. (B)
Leuchtner, H. J. (B)
Lyle, Frank A. (B)
Meyer, John N. (C)
Stanfield, P. E. (C)
Williams, A. D. (C)

INDIANA

Alexander, J. William (B)
Chase, Ray (B)
Nichols, E. Scott (C)

KANSAS CITY

Culig, Ivan C. (B)

LEHIGH VALLEY

Metz, Gerard (B)

LONG BEACH

Chapman, H. E. (B)
Golgart, Lester R. (C)
McGowan, Gordon S., Jr. (C)
Royce, Merrick E. (C)
Sowman, Edward L. (C)
White, Charles A. (B)

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abstracts of CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 25, D. C.

2,594,333—Gas Arc Torch—Gustav K. Medicus, Dayton, Ohio.

The gas-arc torch disclosed by this patent includes a barrel which has converging electrodes therein. Gas-obturating means are at the rear end of the bore of the barrel and manually actuable means slide through said obturating means to regulate the degree of convergence of the electrodes. Independent means are provided for feeding the electrodes into the torch and these means supply electric current to the electrodes.

2,594,905—Arc Welding Electrode—Charles J. Gallagher, Schenectady, N. Y., assignor to General Electric Co., a corporation of New York.

The electrode of this patent includes a nonconsumable cored inert-gas shielded electrode which is capable of starting an arc instantly and maintaining a stable arc. The metal forming the electrode has high heat conductivity and a low melting point relative to the core of the electrode. The core is made from thoria, zirconia or ceria.

2,595,830—Welding Nut—Joseph B. Demboske, Berea, Ohio, assignor to Edward J. Demboske, Berea, Ohio, and Ray E. Demby, Battle Creek, Mich.

The patented welding nut comprises a body having a threaded axial opening with an integral flat flanged base. The flat base has ribs protruding therefrom and tapered both toward the flange perimeter and toward a center recess.

2,596,133—Attachment for Cutting Torches—Benjamin H. Donahue and Frank H. Gallimore, Pueblo, Colo.

This attachment is to position a center pin to a cutting torch and it includes a body having upper and lower offset end portions. The lower offset portion provides a support for a center pin and the upper portion provides means for supporting clamping means for securing the attachment to a cutting torch.

2,596,165—Arc Starting Method and Composition—Harold Spencer Payne, Cleveland, Ohio, assignor to The Lincoln Electric Co., Cleveland, Ohio, a corporation of Ohio.

The new method of this patent relates to the obviating of sticking in starting a weld arc and it includes the preliminary application to the surface to be welded of a composition including granular material a major part of which is ferroso-ferric oxide and a minor part of an alkali metal nitrate. Such composition is applied to the workpiece prior to each new starting of the weld arc.

2,596,453—Method and Machine for Spot Welding—Joseph C. Weidel, Bonita, Calif., assignor to Rohr Aircraft Corp., Chula Vista, Calif., a corporation of California.

Weidel's welding method is for welding a larger to a smaller tube and includes the step of advancing the larger tube into a support fixture composed of material having a large electrical conductance and the smaller tube is advanced into the larger tube until a desired overlap is obtained. An electrode is positioned against the smaller tube in the region of the overlap and electric current ample to fuse a portion of the tube material is provided thereto. The fused tube material is compressed to bring the tubes into engagement.

2,596,951—Automatic Welding Apparatus—Otis Richard Carpenter and Frank W. Armstrong, Jr., Barberton, Ohio, assignors to The Babcock & Wilcox Co., Rockleigh, N. J., a corporation of New Jersey.

This automatic welding apparatus is of the type in which the relative positions of a pair of electrodes are adjusted by mechanism operable by the driven element of a differential gearing having a pair of driving elements and a pair of high-speed direct-current electric motors each connected to one of the driving elements for maintaining the driven element stationary when the motors are driven at equal speeds. Control means are provided responsive to variations in the welding voltage for varying the relative speeds of the motors to rotate the driven element to adjust the relative positions of the electrodes. The motors are operated at speeds in excess of 5000 rpm so that control speed variations represent only a small percentage of the motor speeds.

2,597,153—Welding Through Pressure—Georges Henri Lagarde, La Varenne, and Joseph Bulota, Saint Maur, France, assignors to L'Air Liquide, Societe Anonyme Pour l'Etude et l'Exploitation des Procedes George Claude, Paris, France.

In this patent, a device for butt welding metal pipes is provided and it includes a fixed support for one pipe and a movable support slidably positioned relative to the fixed support for supporting and moving the other pipe in alignment with the fixedly supported pipe. A welding torch is positioned surrounding the pipes at the places of the edges to be welded and a power-actuated reciprocating member is arranged coaxially to the pipes adapted to engage the movable support when moved toward the latter. A ring is positioned around the pipe on the movable support and a compressing spring is positioned between such ring and the power-actuated member. Stop members are positioned in the apparatus on the power actuated member for releasing the ring when the power actuated member is moved toward the movable support to engage it.

2,597,689—Arc Starting System—Alanson U. Welch, Jr., West Townsend, Mass., assignor to General Electric Co., a corporation of New York.

Welch's patent is for apparatus on an adjustable reactance transformer having primary and secondary main windings and a pair of auxiliary windings. One of the auxiliary windings is positioned near one main winding and the other is positioned near the other of said main windings. The auxiliary windings are connected in series with one another and with one main winding. Additional means are provided for adjusting the leakage reactance of the main windings of the transformer. Pairs of supply and load circuit terminals for the windings of the transformer are provided and the welding circuit is controlled by a relay having a pair of normally open contacts and means for closing the circuit contacts in response to the open circuit voltage across the load circuit terminals and for opening these contacts after a predetermined time delay in response to the drop in voltage across the load circuit terminals upon the flow of load circuit therethrough.

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Supplement to the Welding Journal, July, 1952

Stainless-Steel Applied Liners

Review of published and unpublished information on welding procedures used in the fabrication of applied liners; heat treatments, testing procedures and code requirements

by Helmut Thielsch

SUMMARY

Applied liners are composite plates, where a relatively thin sheet of a corrosion or heat-resisting metal is bonded intermittently to a backing steel, usually a commercial grade of mild or low-alloy steel.

Manufacture

In the fabrication of applied liners, the base steel and the alloy liner are, respectively, plate and sheet of the thickness desired for each in the final composite plate. The intermittent bond generally is commercially produced by (1) spot or seam welding, (2) plug welding, (3) strip welding and (4) through welding). Spot and seam welding generally are performed on plates prior to their fabrication into vessels or other structures. The other procedures are primarily used to attach liners into already fabricated vessels or vessel parts. Some of these procedures can be applied to vessels either erected in a shop or already installed in the field.

Heat Treatments

The alloy material is in its fully annealed state with maximum corrosion resistance which can be maintained during application and fabrication. Stress relieving requirements of the carbon steel often can be accomplished with applied liners within the range of temperatures permitted by the ASME Code without deleterious effects to the liner. Austenitic applied liners may be stress relieved at temperatures below 1000° F. (540° C.) by holding at temperature for longer periods of time as permitted by the Codes. Vessels lined with the straight chromium stainless steels, when required, are ordinarily stress relieved between 1150 and 1250° F. (620 and 675° C.) for 1 hr. per inch of thickness.

Testing Procedures

Air-pressure and hydrostatic tests are used most commonly. In the air-pressure test, holes are drilled either through the backing steel or through the liner panels, the former being preferred practice. Air pressure between 5 and 100 psi. is applied between the base metal and the liner for all except those attached by spot or seam welding and the weld joints are covered with water or with a soap solution. Any leaks may then be observed by bubble formation. In the hydrostatic test the lined vessel is subjected to hydrostatic pressures of about $1^1/_2$ to 2 times the working pressure. After the vessel has been emptied and the interior surface dried, a lime-wash coating is applied over the inside surface. Any backseepage of the testing medium within 24 hr. indicates the location of any leaks occurring during the hydrostatic test.

Spot- or seam-resistance welded liners usually are bond tested at pressures up to 2000 psi.

Other variations and methods of testing are also frequently used (see pp. 332-s to 335-s).

Characteristics

Applied liners offer several advantages for the corrosion protection of load-carrying members such as pressure vessels.

1. The process is unique for applying all types of high-alloy and high-temperature materials which cannot always be made up in conventional clad.

2. Liner materials may be inspected to gage requirement, surface finish, chemical analysis and mechanical properties prior to application.

Helmut Thielsch is Technical Assistant, Welding Research Council, New York, N. Y.

This report was prepared under the auspices of the Literature Advisory Committee of the Welding Research Council: G. E. Doan, *Chairman*; T. S. Fuller, L. E. Grinter, C. E. Jackson, E. M. MacCutcheon, R. F. Miller, W. Spraragen, David Swan, R. D. Thomas, Jr., J. L. Walmsley and Helmut Thielsch, *Secretary*.

3. Heat treatment of liner alloys is possible in sheet form for specific purposes such as:

(*a*) Maximum corrosion resistance.
(*b*) Special heat treatment to produce carbide stabilization which insures less sensitization in the heat-affected zone upon welding.

INTRODUCTION

Definition

APPLIED liners are composite plates, where a relatively thin sheet of a corrosion or heat-resisting metal is bonded intermittently to a backing steel, usually a commercial grade of mild or low-alloy steel. In this respect applied liners differ from clad steels where the corrosion- or heat-resisting sheets are integrally bonded to the backing steel.

In the fabrication of applied liners, the base steel and the stainless-steel liner* are, respectively, plate and sheet of the thickness desired for each in the final composite plate. Generally, the stainless-steel liner is bonded intermittently to the base steel by one of four major welding processes. (1) Spot welding or seam welding, (2) plug welding, (3) strip welding and (4) through welding.

Spot and seam welding ordinarily are performed on plates prior to their fabrication into vessels or other structures. The resulting composite plates then are fabricated into the desired vessels by the usual procedures for carbon-steel vessels with the carbon steel providing the load-carrying member and the liner the protective membrane. On the other hand, plug welding, strip welding and through welding usually are used in lining vessels or vessel parts which have been constructed first out of a mild or low-alloy steel. The stainless-steel liner panels are shaped and preformed to fit the shape and contours of the fabricated vessel or vessel parts and then are welded into the vessel. Lining by through welding usually is done in a shop where flat or downhand position welding can be accommodated. This welding equipment is not adapted to horizontal, overhead or vertical position welding for field applied linings. Plug welding and strip welding are performed either in the shop or in the field where manual welding can be applied with the appropriate types of electrodes.

Field lining of existing vessels has been used in oil refineries to combat corrosion since, in this manner, the service life of carbon-steel vessels can be increased considerably. It sometimes is more economical to line existing carbon or alloy steel vessels, which are threatened with destruction by severe corrosion, with suitable stainless-steel liner panels, than it is to construct a completely new vessel out of solid, clad or lined stainless-steel plates.[19] However, the lining of existing vessels often requires special fabricating considerations which differ from those used in the construction of vessels from already lined or clad plates. For example, heat treatments usually cannot be made when a lining is applied to an already fabricated vessel.

In the construction of new equipment the problem of whether to use solid, clad or applied liner construction is more complicated. Each type of construction has a field of application in which it is the least costly of the three and gives satisfactory service.[19] Liner construction applied by plug welding, strip welding or through welding usually is considered to be most economical when the wall thickness of the vessel exceeds $^3/_4$ in.[19] Those fabricators who use spot- or seam-welded stainless-steel liner plates feel that these materials are most economical and competitive when the thickness exceeds $^1/_2$ in. However, in many applications, stainless clad steels and applied liners are competitive for wall thickness between $^1/_2$ and $1^1/_4$ in.

The "liner" sheets usually are specified in thicknesses between $^1/_8$ and $^1/_{16}$ in.; the thicker sizes are preferred where arc-welding methods are to be used. The stainless-steel liners are generally purchased from the mill in the thicknesses, lengths and widths which are required for each vessel.

In applied liner construction the mechanical properties of the lining are not of major importance, instead they are used primarily because of their corrosion resistance. Although heat transfer is important in some cases where stainless clad steels are used at elevated temperatures,[7] this consideration is not of any significance in the majority of cases where applied liners are employed. In fact, since an applied liner with a wide spot or weld spacing is an excellent insulator, the low heat transfer of liners with wide weld spacings may be a desirable feature.[57]

The thickness of the stainless-steel lining material is not included in the computations for the required wall thickness of any lined vessel.[17] Thus, the allowable design stress and the joint efficiency are the same as is used for the base steel for an unlined vessel.[17] On the other hand, vessels constructed out of clad plates may be designed and computed for the total (backing steel plus cladding) thickness, (*a*) when corrosion is not expected, (*b*) provided the joints are made by depositing corrosion-resistant weld metal on the base metal weld to restore the cladding and (*c*) the service temperature does not exceed the limiting temperature for either the stainless steel or the backing material used.

LINING PROCEDURES PRIOR TO FABRICATION INTO VESSELS AND OTHER STRUCTURES

Spot and Seam Welding

In lining by spot or seam welding,[13, 36, 38, 42] the stainless-steel sheet is placed on the backing steel plate and is welded to it. A typical spot-welding operation is shown in Fig. 1. Ordinarily, in spot welding, the spacing between spots specified is between 1 x 1 in. and 3 x 3 in. The close spot spacings generally are desired for high-temperature applications and for applications which

* Many nonferrous metals and alloys can also be readily applied as liners; however, it is not the purpose of this report to cover these materials.

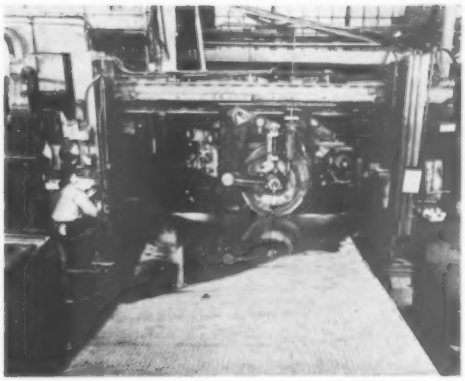


Fig. 1 Typical setup for spot welding of applied liners[13]

experience thermal cycling. In some cases, a nickel sheet 0.010 in. thick is used between the stainless and the backing steels.[13, 28] The nickel minimizes carbon migration as well as dilution of the base steel from the welds.[28]

In seam welding the liner generally consists of several plies of stainless steel each approximately 0.050 in. thick. The purposes of multiple cladding layers are that they provide greater flexibility and that the electrode pressure will be more effective in obtaining a high resistance path so that the current will pass in this area in preference to the longer path through the next adjacent finished weld.[28] The thickness of the liner and the thin intermediate nickel sheet may make a total thickness of about 0.115 in.

The use of spot and seam welding is limited entirely by the composition, thickness and resistance of the stainless and backing steels and by the spacing between the welds.[13] When the uniform spot spacing produces a bonded area of about 15 to 20% of the total metal area, experience has shown that both ferritic and austenitic lining performs satisfactorily in elevated temperature applications.[68] For example, a $1^1/_2$ x $1^1/_2$ in. space between spot centers in either direction results in a bond attachment of about 18% which is adequate for moderate applications of thermal shock at elevated temperatures.[68] For more severe conditions of thermal shock, a spacing of 1 x $1^1/_2$ in. between spot centers which produces an attachment of 22% would be satisfactory.[68] In seam-welded liners approximately 75% of the contact area is welded.[64] These welds are overlapped in the longitudinal direction but not in the transverse direction.

Shear tests on single spot welds show that, for the stainless materials, the strength is equal to that of the liner alloy when the thickness does not exceed $^7/_{64}$ in.[68] Of course, it must be realized that, since the bond is not continuous, the tensile strength of the whole liner is representative of the bonded and unbonded areas. This is apparent from data by Carpenter,[28] Fig. 2, showiug the approximate effects of spot weld center spacing on the tensile load necessary to pull the stainless liner from the backing steel in a 2 x 2 in. wide specimen. In vessels where plates experience internal or external pressures these tensile values have little relevance since the total strengths of the components of the composite plate would be additive. Actually, in design the strength characteristics of the liner material is neglected and the design is based wholly on the mechanical properties of the backing steel.

Heat transfer will depend upon the spacing of the weld attaching the liner to the base metal.

If corrosion should penetrate the lining, or if leaks should occur due to cracks or porosity at any given point, the corrosive medium can find its way through the protective lining and attack the carbon steel. Fortunately, in most refinery services, the products of corrosion seal off pinhole leaks and small cracks. Carbon or coke deposits also may seal off such leaks so that no serious damage is done.[18]

In these spot- or seam-welded alloy linings, dilution may take place at the bottom side of the stainless sheet and result in a lowered alloy composition which should not be significant from a corrosion viewpoint, since it does not reach the surface, but which might cause some embrittlement. The actual amount of dilution depends upon the penetration into the carbon steel of the alloying elements in the stainless steel. Tests of spot-weld nuggets which were analyzed in thickness layers of 0.005 to 0.010 in. generally showed that the extent of dilution is of the order of less than 5% although in some cases it may amount to as much as 10% near the junction.[68] The difference in corrosion properties between the wrought liner and the fused spot-weld nugget often observed in accelerated corrosion tests is believed by some authorities to be largely the result of the effects of a difference in potential, which is established by metallurgical factors other than composition.[68] Similar differences have been noted in the corrosion properties in the wrought and in the cast conditions of the same alloy.[68] On the other hand, corrosion tests by Maier,[24] made on 18-8 (Cr-Ni) stainless-steel plates which were spot welded to low-alloy (Cor-ten) steel backing plates, indicate that the accelerated corrosion attack at the spot welds is the result of the difference in tensile

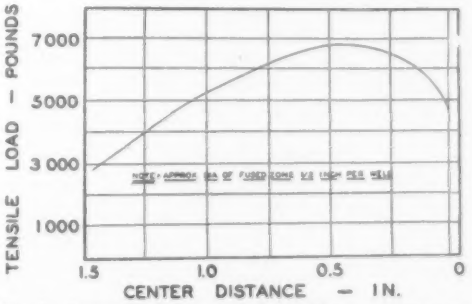


Fig. 2 Approximate effects of spot-weld center spacing on the tensile load necessary to stainless liners from backing steel in a 2- x 2-in. wide specimen[28]

stresses in the stainless steel at the weld nugget. The localized corrosion is reduced by a tempering heat treatment* in the spot-welding machine or by a stress-relieving heat treatment after welding.† Even without any external stress applied to the specimen, a stainless-steel spot weld with high residual stresses is readily susceptible to stress-corrosion cracking in certain solutions.[22]

The formation of the weld nugget results in a reduction of the remaining thickness of alloy which is of the original composition [22] and is in the wrought condition. Some spot-welding procedures can cause the fused nugget to approach very closely to the service side of the liner.[58] These should be avoided whenever possible. When the process is controlled properly an adequate thickness of unaffected liner metal should remain above the nugget of the spot weld.[58] Particularly if the weld is improperly made, the area of liner metal above the weld can become heated during the spot-welding operations and thus unstabilized austenitic stainless steels may become sensitized by intergranular carbide precipitation. If this sensitized zone extends to the exposed outside surface, the stainless steel used in the applied liner will be susceptible to intergranular corrosion.[59] However, by controlling the heat input properly or by flowing water over the surface, quenching results at such a rapid rate that intergranular carbide precipitation at the exposed surface is prevented.[58] Overheating of the stainless-steel surface during spot welding, with subsequent carbide precipitation, may also be prevented by using a high welding pressure and a long "hold" time on the electrode. In fact, by maintaining the electrode in contact with the weld during cooling, a fast rate of cooling is obtained, which cannot be duplicated with an external water spray.[23] Proper control of the spot-welding procedure will also minimize carbon diffusion which is an undesirable feature since, when the carbon content is raised, the diluted zones will show an increase in hardness, as well as lowered ductility and corrosion resistance.[22]

The martensitic and ferritic chromium stainless steels generally are not sufficiently susceptible to intergranular corrosion to require rapid cooling of the welds. In fact, rapid cooling of welds in martensitic and ferritic chromium steels is objectionable, as this would cause excessive hardening and cracking at the bond—particularly when carbon pickup has already occurred.

When the composite plates are to be hot formed by rolling, spinning or other procedures a light fillet-type seal weld should be deposited around the edges of each spot-welded composite sheet.[43] This weld prevents warping at the edges during heating and rolling and also prevents any tendency of the metal to oxidize beneath the edges of the liner sheet.[43] After the composite plates have been formed into the complimentary curved parts of the vessel, the suitably prepared mating edges are welded with procedures similar to those recommended for the fabrication of stainless-clad steel plates.[7]

* The tempering heat treatment of spot welds is a heat treatment given to spot welds wherein after the weld cycle is completed the electrodes are permitted to remain in contact with the weld under pressure for a predetermined cooling time.[21] This is followed by an additional impulse of welding current. This second impulse is usually of lower current and weld time so that the previously made weld is not heated to any plastic stage but instead to a sufficiently high temperature to cause some tempering to occur in the weld nugget.[23] Tempered spot welds will generally exhibit improved mechanical properties over "un-tempered" spot welds in the same material.[23] The selection of the tempering conditions is one that requires much experimentation and usually has to be controlled very closely if used in production.[22]

† The stress-relieving heat treatment consisted of 15 min. at 1150° F. (620° C.).[23] Such a treatment would not be practical for large-scale tank linings.[23]

LINING OF FABRICATED VESSELS

When existing vessels are to be lined in a shop or in the field it is important that detailed drawings are carefully made of the liner panels which are to be fabricated and fitted into the existing structure. In the case of newly erected structures the detailed drawings for the liner panels may be made from drawings of the existing shell.[19] When old vessels are to be lined it usually is advisable to base the detailed drawings upon actual measurements since, during the earlier service of the vessel, some of its dimensions may have changed.[19] Attention should be given to (1) the size of the liner panels required, (2) the size and spacing of the holes (when plug welding is used), (3) details around openings, fittings, baffles and traps (a continuous stainless-steel surface must be installed) and (4) the size and shape of the liner panels to be used in conical, hemispherical or ellipsoidal heads.[19] Design procedures for liner panel and strip layouts and templates for elliptical, curved and uniformly rounded sections have been discussed in detail by various authors.[28, 44, 54]

The liner panels are first cut out and shaped. With old vessels, which are somewhat irregular in shape and can be lined in a shop, it sometimes is preferred practice to delay cutting and shaping the liner panels until the welders are ready for the pieces.[19]

Preforming of the liner panels is advisable where the wall contour of the vessel is irregular.[19] Where the contour is uniformly curved it often is not necessary to roll the liner panels as long as, with proper jacking, the panels are pressed tightly against the inner surface of the vessel.[19, 20]

Prior to lining, the fabricated vessel must be thoroughly cleaned, as otherwise leaks, porosity and other defects in the weld deposits may result. In newly constructed vessels normal cleaning methods should be satisfactory.[19] However, old vessels must be carefully cleaned so that no rust, scale, old paint, aluminum coatings, sprayed metal, grease, oil, coke, dirt or other foreign matter remain on the inner surface of the shell.[19] Sand-, grit- or shotblasting is probably the best and most economical method to use with old vessels and also is often used on newly constructed vessels.[16, 19, 21, 26, 29, 34, 45, 52] Crushed flint-type sand seems to be preferred for this purpose by some engineers.[19]

In riveted vessels, which are to be lined, it may be necessary to caulk or seal-weld the joint and rivets when there is a tendency for oil to seep from the joints after cleaning.[21] The field welding of rivet heads on riveted pressure vessels is not good practice because of the possi-

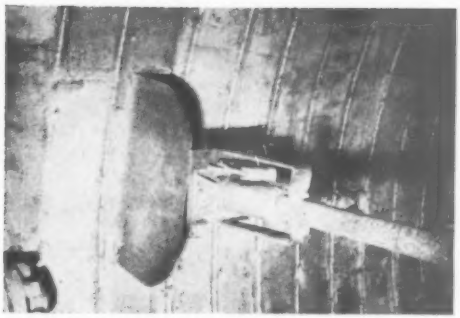


Fig. 3 Hydraulic jack arrangement for holding liner panels against vessel wall during welding[16]

ble cracking of the weld when stresses from pressure are applied.

It also is good practice to chip and grind off any projecting areas on the inside of the shell and repair by arc welding any cracks or depressions which are located where the through, plug or strip welds are to be made.[16, 21]

Prior to welding the preformed liner panels to the fabricated vessel, it is very important that each panel section be carefully jacked in place and/or tack welded.

Jacking procedures usually consist of pressing the preformed liner plate against the inside shell of the vessel by means of a suitable hydraulic jack arrangement.[16, 19] In the example shown in Fig. 3, the jack was fastened onto a base with a 4-in. wide and $^1/_2$ in. thick plate contoured to the same curvature as the wall of the vessel.[16] The moving head of the jack was inside a pipe which was welded to the base of the jack. A smaller pipe was inserted in this pipe so that, when the jack was raised, the smaller pipe was pushed against the opposite wall of the vessel and thus held the liner strip to be welded tightly against the wall.[16] In the jack assembly shown in Fig. 3, a baffle of lightweight steel was welded on one side to protect each welder from welding flash on the other side of the jack.[16] The portion of the liner strip which is being pressed by the jack against the vessel wall can be welded by two welders working together by depositing a continuous fillet weld simultaneously on each side of the strip.[16] When welds the length of the jack shoe have been deposited, the jack is moved down the sheet and the procedure started again.[16] Short welding runs and back stepping help to minimize distortion in the sheet.

Since this jacking procedure allows deposition of only relatively short welding runs, tack welding is often preferred—even though some jacking may be necessary to hold the liner strips against the backing steel during the tack welding operation. The final welding can be made in relatively long runs and without the use of the hydraulic jack assembly previously discussed. When tack welds are used, they should be made every 3 in. along both sides of the liner panels.[60] The surface of each tack weld should be ground down in order to insure that the weld beads deposited subsequently are free of porosity.[60]

Another procedure which may not require tack welding makes use of a so-called spider with 6, 8, 10 or more radial arms.[19] This will hold in place a full course of strip lining or several complete rows of panels with holes for plug welding. Lengths of tubing welded to a steel hub make a good spider that is not too heavy. Light jacks attached to each arm provide adjustment and pressure and a shoe on each jack will distribute the pressure.[19] Vertical positioning is made easy by suspending the spider by a rope or cable from the top of the vessel,[19] particularly where horizontal strips are applied to vertical cylindrical vessels.[58] With large enough shoes and a sufficient number of long arms pressure can be practically continuous around the periphery.[58]

Plug Welding

In bonding by plug welding [13, 19, 26, 28, 29, 32, 34, 50] the stainless-steel lining is attached by welding each liner panel to the base plate through holes punched or drilled through the stainless sheet material. An example of plug welding of a vessel section is shown in Fig. 4.

The stainless-steel liner panels have to be preformed and shaped to conform to the interior contours of the vessel which is to be lined. The size of each liner panel is limited by the largest opening in the vessel. Panels 24 to 36 in. wide by 60 to 120 in. long ordinarily are used.[19]

Although the steel producers charge extras for larger

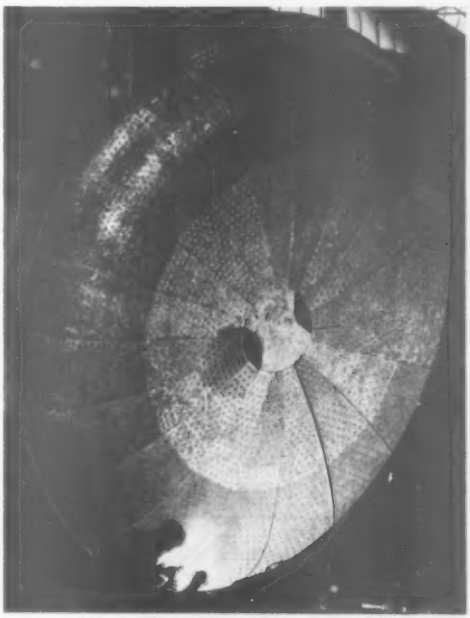


Fig. 4 Plug welding of vessel section[13]

sizes, the edge welding requirements, which often more than offset the size extras, would be reduced[19]—if larger sizes can be used. Prior to welding, the liner panels should be carefully formed and jacked in position to assure proper fit up.

The holes usually are prepared by punching or drilling. In stainless-steel liner panels over $^1/_8$ in. thick, the edges of the holes are occasionally chamfered, as illustrated in Fig. 5. The diameter of the holes varies between $^1/_2$ and 1 in., their size generally depending upon the thickness of the liner panel and the welding procedure used. Holes of less than $^1/_2$ in. diameter may cause welding difficulties by shorting of the arc, resulting in excessive porosity and poor bonding between liner and shell, and by flux interference.[19, 34] Diameters over 1 in. tend to promote excessive dilution of the weld metal.[19, 34]

For vessels which are to be operated at elevated temperatures, the following empirical spacings between holes are generally used:[19]

Maximum operating temperatures of vessel		*Maximum distance between centers of holes, in.*
°F.	°C.	
Up to 450	Up to 230	Up to 6, preferably not over 4 in.
450– 750	230–400	4
750– 850	400–455	$3^1/_2$
850– 950	455–510	3
950–1000	510–540	$2^1/_2$

For austenitic stainless-steel liner panels, the recommended distance between the holes should be decreased when the vessel experiences temperature cycling or severe temperature gradients. In vessels operating under vacuum the spacings should not exceed 3 to 4 in.[19] Greater distances, up to as much as 12 in., have been used for room temperature service when cyclic temperature stressing was absent.[34]

After the liner panel has been placed in position and has been properly jacked at its center, a tack weld is made through one of the center holes by running a bead across the bottom of the hole.[21] The jacking arrangement is then moved to allow tack welds to be made about every third hole—progressively outward from the center.[21] The edges of the liner panel should be tack welded to the shell with 1-in. long welds about 6 in. apart.

Shielded-metal-arc welding processes ordinarily are used for plug welding. However, semiautomatic welding with inert-gas shielding or submerged-arc welding has also been successfully employed in a number of cases. Particularly, inert-gas metal-arc welding with consumable stainless-steel electrodes has been used with great success.[58, 64] Whereas inert-gas welding is applicable to all positions except overhead, submerged-arc welding is limited to downhand welding with some special applications of horizontal welding.

The "ring-welding" procedure, illustrated in Fig. 6, generally is preferred for liner panels up to $^1/_4$ in. in thickness.[19, 24, 42, 58] Ordinarily, the welding should be done in two stages. First the welder should "ring" the hole for fastening the liner, remove the slag and inspect the weld. The remaining unwelded center section should then be filled in (sealed) in a separate operation.[19, 24] Hole diameters of $^3/_4$ to 1 in. usually are recommended for this two-step procedure.

When highly skilled welders are used, the "ring" and "fill-in" welding may be combined into one operation.[19] In this case, a $^1/_2$-in. diameter hole should be used for liner panel thicknesses up to $^1/_{16}$ in. and a $^5/_8$-in. diameter hole for thicknesses between $^1/_{16}$ and $^1/_8$ in.[19]

Chamfered holes can be used when the liner panel thickness exceeds $^1/_8$ in. (see Fig. 5). Although chamfering represents a relatively costly procedure, it helps to produce strong and sound plug welds.[19] Nevertheless it is rarely used.[57, 64]

Plug welding should start in the center of each liner panel and progress to the outer edges in all directions. This procedure tends to minimize residual stresses.[19, 24] After all plug welds have been completed in one liner panel, the adjacent sheet is plug-welded and the edge welds are made to join the panels using the procedures discussed under strip welding. Good fit-up of the liner panels is necesary if butt welds are used. It is less important when lapping is used.[19] Particularly when considerable experience with plug welding procedures is lacking, lapping of the edges is more economical. Good results also are more certain with edge lapping—even though the material cost is increased because of the larger liner-panel sizes required.[19]

Because of the difficulty of making plug welds that are sound and tight, particularly when highly skilled

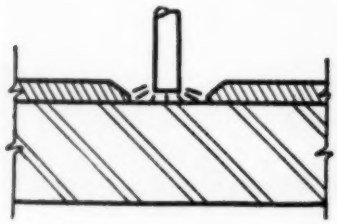


Fig. 5 Plug welding of chamfered holes[19]

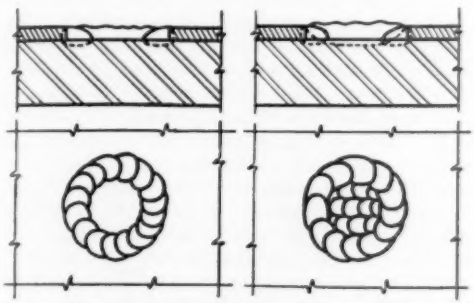


Fig. 6 Ring welding procedure recommended for plug welding[19]

welders are not available, through welding and strip welding are used more commonly than plug welding. Other disadvantages of plug welding arise from the fact that it is difficult to force large stainless sheets against the walls of fabricated vessels for close contact on all edges and holes; this generally results in distortion, warping and twisting.[50, 53] Distortion may be minimized by overlapping the edges of the stainless sheets. However, since this represents a waste of materials, other methods such as strip lining, where butt-welding procedures generally are used, are preferred.[53] The strength of plug- or spot-weld linings, particularly at elevated temperatures, also is believed to be considerably below those of linings produced by other methods.[50] Finally, the required punching of holes is an item of considerable expense.[14]

Plug welding through the backing steel instead of through the liner also has been used occasionally, as for example, in the case of lining dough mixer bowls.[49] This method has the advantage of giving a smoother stainless-steel surface.[59]

Strip Welding

In strip welding, also known as strip lining,[13, 16, 19, 26, 28, 30, 32, 48, 50, 53, 54, 55, 65] the stainless steel liner is attached to the base plate by means of welds that join adjacent sheets to each other as well as to the backing steel, as illustrated in Fig. 7. The lining is in the form of strips of such width that no attachments are required in the interior of the panel.

The strip-welding method is used commercially to a considerable extent since stainless steels can be readily welded to the base steel. One exception is for those stainless-steel types which exhibit hot-shortness and consequently are susceptible to cracking during cooling because of the restraint offered by the thicker base steel plate. Thus, special precautions may be required when strip welding the columbium- and copper-bearing stainless steel types.

Fig. 7 Strip welding of vessel[13]

Strips which are to be installed into already fabricated vessels have to be preformed into shapes and sections conforming to the dimensions of the vessel. The length of the strips generally varies from 24 to 40 in. for field-applied liners or from 24 to 120 in. for shop-applied liners, depending on the type of equipment and construction. The width ordinarily varies between 3 and 6 in. The narrower widths are used for liners which are operated at high temperatures and/or which experience thermal cycling.

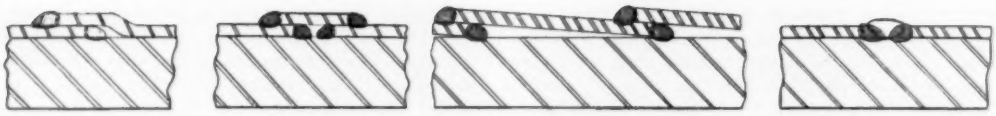
For vessels which are to be lined with stainless-steel liner sheets less than $^1/_8$ in. thick and which are to be operated at elevated temperatures the following empirical widths of strips generally are used:[19, 29, 33, 57]

Maximum operating temperature of vessel		*Maximum strip widths*	
		Chromium stainless steels, in.	*Chromium-nickel stainless steels, in.*
° F.	*° C.*		
Up to 450	Up to 230	Up to 6	Up to 6
450– 750	230–400	$4^1/_2$–5	3–4
750– 850	400–455	4	$2^1/_2$–3
850– 950	455–510	$3^1/_2$	2
950–1000	510–540	3	2

The width should be further decreased when rapid temperature cycling occurs or when steep temperature gradients are present.[33] On the other hand, for low-pressure, low-temperature, low-cycling service spacings up to 24 in. have been used with no apparent trouble.[62]

The relative thickness of the liner strip and the backing plate also must be considered. Thus liner strips used on very heavy steel should be narrower than those used on relatively light plate.[15] Because of their higher thermal expansion austenitic stainless-steel liner strips would be more susceptible to buckling than the martensitic and ferritic stainless steel types such as Types 410 or 430. For that reason the widths for austenitic stainless-steel liner strips should be somewhat narrower. In vessels operating under vacuum the strip widths should not exceed 3 to $4^1/_2$ in.,[19] the narrower values applicable to the austenitic stainless steels.

Instead of solid austenitic stainless-steel lining strips, austenitic stainless clad steel strips have been used occasionally as lining in carbon and low-alloy steel vessels.[64] The reason for the selection of the clad material is that increased strip widths can be used over the fully austenitic lining materials.[64] For example, $^3/_8$ in. thick, 20% Types 304 and 347 stainless clad strips, 20 in. wide and 10 ft. long were used successfully in applications experiencing severe thermal cycling, where ordinary solid strip linings had failed.[64] Generally, however, this would not be an economic procedure.



(A) Lap or joggle (B) Butt-strap (C) Shingle (D) Fillet-butt

Fig. 8 Illustration of major types of strip linings

Various arrangements have been suggested for the strip linings. In cylindrical vessels, the strips generally are applied perpendicular to the length of the vessel. However, parallel arrangements also are used particularly in conically shaped vessels. Dished ends are lined with parallel,[30, 53] herringbone[32, 50, 54] or other arrangements. The herringbone pattern seems to be preferred[54] because, in this procedure, there is little tendency for the welders to lap or shingle the strips.

Strip linings can be applied either in the shop or in the field. Moreover, not only new vessels but also vessels which already have experienced service may be lined by these procedures.[15] Thus, vessels may be lined when they are to be changed from noncorrosive service to one in which corrosive solutions or vapors are encountered.

Strip-lined construction is illustrated in Fig. 8. The use of the different types of cover welds (lapping), illustrated in Figs. 8 (*A*) to 8 (*C*), prevents detrimental effects which might be caused by weld-metal dilution.[13, 19] Fit-up is not a problem and sound welds can be made even with welders who are not highly skilled.[19] Crevice corrosion can occur when the welds are not made properly but is less likely with the lap methods than with the butt methods.[19] These lapping procedures are also relatively more costly than the fillet-butt welding procedure shown in Fig. 8 (*D*). Thus, in the butt-strap method (8 (*B*)) four weld deposits are required for each joint.[19] The lap welds with formed (8 (*A*)) edges require a special forming operation.[19] In the shingle method (8 (*C*)) it is difficult to make the lapping edge properly so it will meet the flat surface of the lapped strip.[19] Morover a greater amount of stainless steel lining material is needed for the lapped joints. The ridged edge effect also may cause some inconvenience in vessels which, periodically, must be cleaned thoroughly.[19] Welds which have been covered by overlapping cannot be inspected.[25] Finally, lapped linings will not withstand as high a hydrostatic force tending to pull them loose from the base plate as will either the plug welded or the fillet-butt welded strip lining installations.[14]

The "three-bead" fillet butt-welding procedure, illustrated in Fig. 8 (*D*), generally is preferred to the lapping procedure. Detrimental effects which may result from dilution* usually are prevented by use of a higher alloyed electrode such as 25–12 or 25–20 (Cr-Ni) in welding stainless liners. A more detailed outline of this "three-bead" procedure, as generally used in the welding of liner strips, is given in Fig. 9.[33] This "three-bead" method appears to reduce the tendency of the edge of the liner to pull away from the vessel wall as may result with the "two-bead" method, see Fig. 10, when the second bead is applied both as a fillet and a joining weld.[16]

When welding the relatively light liner plate to a heavy steel backing with either the two- or three-bead method, the austenitic stainless-steel fillet welds attaching the lining to the backing steel exhibit a tendency for interdendritic cracking at the base of the weld.[61] In the two-bead method, especially in operations experiencing thermal fatigue, this base crack is sometimes extended to the surface. With the three-bead method, this type of cracking is minimized because the extra cover pass penetrates into the lower fillet weld.[64]

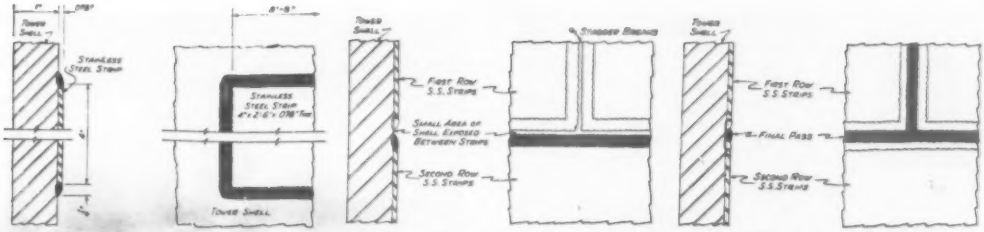
A space of $^1/_4$ to $^1/_2$ in. between strips is the general practice. Moreover, after proper welding of the two fillet weld beads, a $^1/_8$ in. wide area of uncovered shell material should remain which is filled in subsequently by the third "cover" bead.[25]

Recommended welding conditions are given in Table 1.[19] These values will differ somewhat with the different types of beads such as fillet welds that join the stainless liner strip to the backing steel and the cover or butt welds.[19] It is advisable to use the lowest current that will give proper penetration.[19] The welding speed should be adjusted to produce sound weld metal.[19] The larger electrode sizes shown for each lining thickness can be used if the welders are highly skilled. Otherwise, the smaller electrode sizes are recommended, sacrificing some speed for better assurance of weld soundness.

Flat welding generally is preferred. Vertical down welding is more difficult since during deposition of the fillet welds there is a tendency, with all stainless-steel arc-welding electrodes, for the slag to run ahead of the weld, thereby preventing the welder from seeing his work.[33] Because the fluidity of the slag varies with the composition of the coating material, considerable differences in fluidity may exist among various brands of stainless electrode materials and coating types.

In most field-lined vessels there is more vertical and horizontal welding than flat welding. When vertical welding is used, upward welding results in better weld deposits and fewer leaks than downward welding. When lining a vertical drum a circumferential strip pattern is preferred,[57] if lapped an inverted shingle pattern should be used,[57] as illustrated in Fig. 11. Usually, after one row of strips is applied around one-half

* A rather detailed treatment of dilution was given in a previous review.[3]



FIRST STEP. The first strip is applied horizontally and welded to vessel wall completely around all the edges. The weld bead then is deslagged, inspected or tested. Any defects are rewelded and again deslagged. The weld bead firmly fastens the stainless strip to the vessel wall and seals it off completely

SECOND STEP. After completion of all steps in welding the first liner strip, as above, the second liner strip is applied. It is so spaced from the previously applied strip that weld beads of the second strip fasten the stainless steel direct to the vessel shell; that is, the weld bead of the second strip should not lap over into the weld bead of the previously applied strip. The weld beads of the second liner strip are deslagged, inspected and repair welded as in the case of the previous liner strip

FINAL STEP. After all the liner strips have been individually welded to the shell as in the steps above, the weld beads are cleaned by chipping and, preferably, by sandblasting (the sand brushed or blown off), inspected by the refinery inspector, repair welded where necessary, deslagged and again inspected. Then, and only then, is the third or final weld bead deposited. The third weld covers the bare vessel wall exposed between the previously applied beads. This bead is deslagged and patched by the welder as applied and finally inspected by the refinery inspector

Fig. 9 Welding procedure recommended for strip welding[33]

the circumference, the vessel is turned on its side and the adjacent row is started with the short cross seams staggered.[16] After each liner strip is welded completely around with a fillet weld, the slag is chipped off, brushed with a stainless-steel wire, and the weld is inspected and tested for defects and leaks.[16, 33] Any defects present are chipped out and rewelded.[16, 33] After all fillet welds are found to be sound, a third "butt" weld is deposited between and covering the previously applied fillet welds, as illustrated in Fig. 9.[13, 16, 33] A slight weaving motion for the third "cover" bead generally is preferred.[25] Too much weaving may cause undercutting.[61]

Table 1—Recommended Electrode Sizes, Welding Speeds and Current Settings for Shielded-Metal-Arc Welding of Liner Panels[19]

Welding position	*Thickness of liner strip, in.*	*Electrode diameter, in.*	*Welding speed, ipm.*	*Welding current, amp.*
Horizontal and downhand	1/16	3/32	13–15	65
		1/8	15–17	90
	1/8	1/8	12–14	90
		5/32	15–17	125
	3/16	5/32	9–11	125
Vertical and overhead	1/16	3/32	6–8	50
	1/8	1/8	5–7	65
	3/16	1/8	4–6	80

The welder, in order to keep "ahead" of the slag, often is tempted to increase the welding current so that he can weld more rapidly.[33] This, however, is undesirable since excessive heating during welding reduces the subsequent rate of cooling of the weldments. This is particularly detrimental in stainless steels susceptible to hot shortness and/or intergranular carbide precipitation.

All weld deposits made in the course of lining should be ground or chipped or thoroughly brushed with a stainless-steel wire brush to remove all remaining weld slag.[40] Isolated spots on the surfaces of the strips damaged by accidental arc strikes should be repair welded[40] since they are a common source of microcracks.[61] Accidental arc strikes may result from arcing from improperly insulated electrode holders.[64] Weld splatter should be removed by buffing, grinding or chipping.[40] However, care should be taken that not too much liner plate material is removed. The use of antisplatter compounds may be effective in minimizing weld splatter.[64]

Fig. 10 Section strip welded with "two-bead" and "three-bead" procedures illustrating "pull-away" when two-bead procedure is used[16]

Through Welding

In bonding by through welding[13] the liner panel is attached by depositing a submerged-arc weld along the edge of each panel and also a series of submerged-arc welds through the liner sheets, fusing through the liner material and penetrating into the base steel. A typical submerged-arc welding operation is illustrated in Fig. 12. Because of this welding through the liner plates, this process is known generally as *through welding* or *plowed-through* lining.

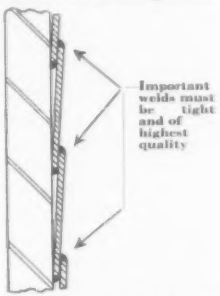


Fig. 11 Inverted-shingle type of lining allowing downhand welding on vertical surface[52]

Through-welding liner panels which are to be

Fig. 12 Submerged-arc welding of vessel[39]

installed into already fabricated vessels have to be preformed into shapes and sections conforming to the requirements of the vessel. Panels 18 to 24 in. wide by 36 in. long ordinarily are used. Moreover, prior to the submerged-arc welding these preformed panels have to be carefully held in place with suitable jacks and tack welds. As illustrated in Fig. 13, submerged-arc plug welds can be made to tack the liner sheets in place.[39] The distance between the centers of these plug welds is usually about 8 in. They are made on the same layout lines subsequently used for through welding, when these plug welds are welded over.[39]

The "through" weld runs are generally spaced about 3 to 5 in. apart.[37] The depth of penetration may vary by about plus or minus $^1/_{64}$ in. and is difficult to hold uniform. However, it generally is not critical. Thus good bonding can be obtained with a penetration of about $^1/_{16}$ in. which represents the usual practice.[39] The composition of the resulting weld metal generally consists of about 40% electrode metal, 40% cladding metal and 20% backing-steel metal, as illustrated in Fig. 14 for Types 405 and 410 lining materials.[48] Because of the dilution with the backing steel, it is desirable to use electrodes which have a higher alloy content than the lining material. However, in the case of Types 405 and 410 lining materials either 25–12 (Cr-Ni) welding wires or 25–20 (Cr-Ni) wires are used. The submerged-arc welds are made either on the initial flat plates or after the plates have been fabricated into cylinders. In the latter case, which represents the preferred practice, the welds are made around the circumference of the vessel. The vessel has to be rotated so that all welds can be made in the flat position.

Fig. 13 Plug welding of stainless-steel liner panels prior to through welding[39]

The through-welding process is now being used by an increasing number of fabricators.

Other Methods

Spot welding for shop lining of fabricated vessels is now being used successfully by several fabricators.

A recently developed "poke welding" gun,* based on the inert-gas shielded-arc welding process, also has been used with some success. This gun fusion welds two lapped pieces of metal without requiring punching or drilling of holes in either piece.[19] Although the resulting weld may resemble actual resistance spot welds[19] these "spot" welds are fused through the liner thickness and present a cast structure.[61] A properly made spot weld is not diluted at the outer surface.[61] Under laboratory conditions, these welds can be made with ease; however, in working on the lining of vessels, there is a great possibility of excessive dilution on the surface which is the result of the high heats and subsequent melting of the stainless-steel liner.[64]

It is important in this "poke welding" process that the liner panel and the backing steel shall be in intimate contact.[19] However, not as much pressure is necessary

* A discussion of this welding process is given in a subsequent review.[19]

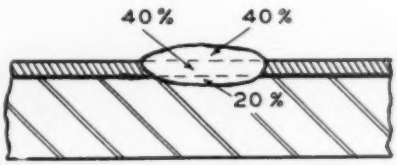


Fig. 14 Schematic sketch illustrating dilution of weld metal deposited by through welding

as is required for resistance spot welding[19] so that the ordinary jacking arrangements discussed earlier can be used. Maximum thicknesses of the liner panels through which the gun will weld are $^1/_{16}$ in. in the vertical and overhead positions and $^1/_8$ in. in the downhand position.[19] It is likely that this method may not work too satisfactorily for lining badly corroded vessels that have relatively rough interior surfaces.[19]

Some equipment is now occasionally lined by stud welding a stainless stud to the liner panel, drilling the backing material and bolting the liner plate to the vessel, as illustrated in Fig. 15.[14, 64] Although this process does not account for a large volume, it is becoming more and more important commercially.[64]

Weld-Metal Deposits

Deposits of stainless-steel weld metal (overlays) are often used at locations where, because of inaccessibility, it would be difficult or even impossible to apply liner panels.[21] For example, such weld overlays are used near pipe inlets, manholes and other areas where the base steel has not been covered with liner panels.

Deposit welding of large sections by shielded metal-arc welding processes does not seem to be too desirable because of the dangers of the formation of slag holes and porosity, of excessive dilution and of the undesirability of surface irregularities and variations in stainless-steel weld metal thicknesses which may occur.[16] Moreover, high internal stresses are introduced into the shell by this procedure.[21] Consequently, overlaying by this process has been used only to cover relatively small areas such as those mentioned above.

In a few instances, a Type 347 stainless-steel weld-metal deposit has been applied on the inside of large forged-steel pressure vessels by submerged-arc welding with two separate electrodes which feed the same weld metal pool.[66] The vessels were rotated and the weld beads were deposited circumferentially in the flat position. The two welding heads were mounted on a boom which fed into the vessel from the open end at a controlled rate of feed and resulted in the desired overlay of concentric stainless steel weld beads.[66] Dilution of the stainless-steel weld metal by the base steel amounted to less than 10%. Test specimens made with this so-called series-arc technique indicate a corrosion resistance comparable to that of solid Type 347 stainless-steel material.[67]

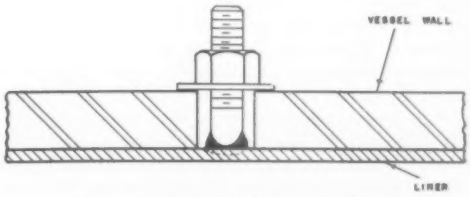


Fig. 15 Liner attached by stud welding[14]

Nozzles and Manholes

When lining vessels it is frequently necessary to line nozzles and manholes.[57] For large openings, liners should be used which are flanged on the inside of the vessel, so that the flange is welded to the vessel liner.[57] These liners will have to be fabricated in sections so as to go into the vessel. For small nozzles, cylindrical liners should be used which extend into the vessel.[57] On the inside a boundary ring or pad of the lining material should be welded to both the nozzle and vessel in a manner similar to the practice of installing reinforcing pads around nozzles.[57]

CHARACTERISTICS OF THE BOND ZONE

Since lined vessels generally are used in corrosive service it is important that the welding procedures and materials used prevent excessive dilution of the weld metal since this might seriously reduce the corrosion resistance at the welds. Generally, when considerable dilution is expected to occur, electrodes of sufficiently higher alloy content than the stainless-steel lining material are used to prevent any detrimental effects which may result from such dilution. In spot- and seam-welded liners some dilution at the bond generally is not detrimental so long as brittle intermetallic phases do not form in the fusion zone and so long as the dilution does not reach the surface of the stainless-steel lining.

Noticeable carbon diffusion* may occur across the intermittently bonded welds from the mild or low-alloy backing steel into the stainless-steel liner plates when the vessel is exposed to temperatures at which the diffusion rates of carbon in steel are appreciable, usually above 1050° F. (565° C.). When such carbon diffusion has occurred the backing steel underneath the weld usually contains a narrow decarburized (ferrite) zone and the stainless-steel weld metal above the bond contains a narrow zone of higher carbon content, generally evidenced by intergranular carbide precipitation. Ordinarily, this carbon migration and intergranular carbide precipitation is not detrimental since it does not reach the surface of the liner panels. Moreover, although the decarburized zone in the backing steel tends to be weaker mechanically, it rarely fails. Only unusually severe thermal and mechanical fatigue may cause actual failure through this zone.

HEAT TREATMENTS

Spot- and Seam-Welded Plates

It is preferable that the reader consult the manufacturer of alloys for the most suitable temperature ranges for hot forming and stress relieving. It is very often necessary to specify that the alloy liner sheet material be suitable for certain hot-forming or cold-forming operations in order to assure that the alloys

* See also the more detailed discussions given in previous reviews.[5, 7]

will perform satisfactorily. Suitable temperatures for the forming and stress relieving of spot- and seam-welded plates for stainless steel are as follows:[48]

Hot forming: For austenitic alloy 1400 to 2000° F. (760 to 1095° C.).

Stress relieving: For austenitic alloy 1000° F. (540° C.) max.

For straight Cr steels: 1100 to 1200° F. (595 to 650° C.).

The reader is advised to refer to the latest codes covering nonferrous and high alloys for further information affecting alloys for pressure vessels.

Lined Vessels

Stainless-steel liner materials are usually furnished in the fully annealed condition providing maximum corrosion resistance which must not be seriously reduced by the fabrication operations or the service.

If the backing steel requires pre- or postheating in order to obtain a good weld, the same practice should be followed with respect to preheating and postheating as though the vessel were not to be lined.[15] Stress relieving requirements of the carbon steel can be accomplished with applied liners within the range of temperatures permitted by the ASME Code without deleterious effects to the liner.[60]

Vessels lined with austenitic stainless-steel liner panels are stress relieved, when required, at temperatures below 1000° F. (540° C.) by holding at temperature for larger periods of time as permitted by the Codes.*, [60]

Vessels lined with the straight chromium stainless steels, with the exception of Type 405 and Type 410 (with 0.08% max. carbon), constructed under the ASME Boiler Code rules must receive a stress-relieving heat treatment, even when welded with austenitic stainless-steel electrodes.[17] Ordinarily, stress relieving temperatures between 1150 and 1250° F. (620 and 675° C.) for 1 hr. per inch of thickness should be used.

It is necessary to test the liner after stress relieving. Leaks are usually found and some welding is usually required even though the vessel was stress relieved.[18]

TESTING PROCEDURES

The tests for applied liners may be divided into various procedures which depend upon the application for which the lined vessel is intended and the importance which cracks and leaks may have on the performance of the vessel. In the Interpretations of the ASME Boiler Code[17] a test for tightness of the lining is recommended, but the details of the test are left to be a matter for agreement between the purchaser, the inspector and the fabricator. The reason for this is because of the different service applications for lined vessels.

The presence of cracks may be determined by means of visual, radiographic, magnetic particle procedures or by fluorescent penetrant inspection.[41]

"Ringing" Test

In the "ringing test"[40] the liner strips are tapped in order to disclose the presence of any liquid which may have penetrated behind it.

Air-Pressure Tests for Strip Lining

A commonly used method consists of drilling and tapping holes through the backing-steel plate up to, but not through, the liner plate. To prevent the danger of drilling through the liner panels, this is often done before they are attached.[57] The hole generally should be large enough to receive a $^1/_8$-in. pipe nipple. The tapped portion of the hole should be drilled only deep enough to obtain 3 or 4 threads.[34] The hole then should be continued with a $^3/_{32}$- or $^1/_4$-in. diameter drill.[34]

The distance between the drill holes will vary with the severity of the service application. In strip-lined vessels such holes ordinarily are drilled under every 4th to 10th liner strip. Pressure between 5 and 30 psi. is then applied between the backing plate and liner strip by attaching an air hose to the tapped holes.[18, 21, 32, 52] During the test, the weld seams should be hammered lightly to loosen any trapped-in slag.[15] The absence of leaks can be assumed if the applied air pressure remains constant.[15] A somewhat more reliable procedure consists of placing several inches of water in the vessel and locating any leaks in the liner weldments by bubble formation.[18] The vessel can be rotated in order to check the entire shell sections.[18] Instead of water the welds may be covered with a soap solution. Ordinarily leaks may then be observed by the formation of soap bubbles.[18, 34] One difficulty frequently experienced with these testing procedures is that the leak may occur in the welds between different sections of the liner. As a result, trouble is sometimes experienced in locating the leaks as a leak may show up several liner panels away from the one behind which the test hole is located.[18]

It is sometimes practiced to plug the drilled holes after testing.[18] On the other hand, they may be left open to serve as the *telltale* or *weep* holes discussed hereafter. When the vents are left open, a valve is usually attached and is also left open. A tube is generally attached to the valve which extends far enough from the vessel to be in plain sight to disclose any leakage.[61, 64] If a leak should develop while the vessel is in service the valve is closed.[64] During the next shutdown of the vessel the defective liner section is then repaired.

* Actually, the need for postheat treatments is controversial. Many authorities feel that the welding of an austenitic stainless steel lining does not induce residual stresses of sufficient magnitude to justify stress relieving after the lining has been applied.[15,19] In fact, the austenitic stainless-steel liner material, quite likely, would have more than enough ductility to relieve stresses mechanically. Moreover, because of the differences in the coefficients of expansion between the austenitic stainless-steel liner and the base plate, as much stress can be put back in by cooling from the stress-relieving temperature as was there before.[19]

Instead of drilling the test holes through the backing steel plate, some manufacturers drill the hole through the liner panels and make the test simply by holding an air hose over the hole.[18] Leaks are indicated by bubble formation through a soap solution applied over the weld seams. This is a quicker and more convenient testing procedure and is more economical, especially on thick-walled vessels.[18] After testing, the holes are again welded shut. Nevertheless, in spite of the foregoing advantages this procedure is not as satisfactory as is the use of telltale or weep holes through the base plate.[64] Moreover, it is not easy to make a tight stainless-steel weld in the hole in the liner plate.[64] Finally, during operation there is no way to check if these welds are tight and if there is seepage behind the liner plate.[61, 64]

The procedure used by Collins, Baisch and Velden[16] consisted of drilling into each liner panel a small hole which was tapped with No. 10 N.F. threads prior to welding the panel to the vessel. A large special nut was made which had a $^1/_4$-in. pipe connection on the top side. A small hole of the same size as the test hole in the liner panel was drilled through the nut and was tapped for No. 10 N.F. threads. A bolt was then screwed into this hole after which the head of the bolt was cut off so as to leave a stud $^3/_{16}$ in. long sticking out of the nut. A small hole for the air passage was then drilled through this stud. A $^1/_{16}$-in. thick rubber gasket was fitted at the base of the stud to provide cushioning and to reduce the frequency with which the threads on the stud were stripped. This left the effective stud length the same as the plate thickness. Finally, a pressure gage and a pressure reducing valve were fastened onto the top of the large nut and connected to the air supply. Through this attachment air pressure of 15 psi. was then applied underneath each liner panel while the weld seams were brushed with a weak solution of soap[16] or a suitable wetting agent.[60] Air leaks were observed readily by the formation of bubbles.[16] After the leaks in the weld seams around the respective liner panel had been repaired and tested again the attachment was removed and the test hole was welded shut. Originally each test hole was chamfered. However, because of their small size, filling these holes with weld metal often resulted in slag holes. The best procedure seemed to be to deposit several weld beads over the test hole rather than to fill it in.[16] A later procedure employed for filling the test holes was to thread a small rod of a similar stainless-steel grade and screw it into the test hole before welding over it.[60] The rod was broken off at the surface of the liner simply by bending it back and forth.[60] Grooving the rod at intervals made it easier to break the rod at the desired location.[60]

Fluorescent Penetrant Inspection

Fluorescent penetrant inspection has also been used with good success, usually to check for pinholes and cracks after welding and before the hydrostatic or air-pressure test.[63] It is sometimes made as final test after a vessel has been passed by air and soap tests on the individual liner panels.[60] Collins,[60] for example, placed 2 oz. of General Dyestuff Corp. Uraine SS in a 2000-cu.-ft. digester and then brought the vessel up to full pressure with steam. The vessel was kept under pressure for about 1 hr. The pressure was then slowly reduced to atmospheric conditions allowing most of the dyestuff to be flushed out in the process.[60] The vessel then was brought up to pressure which subsequently was rapidly diminished by "blowing." After the vessel had cooled the welds were examined in the dark with an ultraviolet lamp.[60] Any amount of dyestuff which had leaked back from behind the liner plate was revealed quite readily.[60] The major difficulty with this procedure is that slag on the weld deposits also holds the dyestuff, so that all slag must be removed before the final examination.[60]

Vacuum-Chamber Tests

In the vacuum chamber test,[27] a vacuum chamber, generally made with a soft rubber base to give air-tight contact with the plate, is placed over the welded portion of the lining after the application of soap suds. Upon the application of the vacuum, any leakage may be observed through an inspection glass which is mounted in the top surface of the vacuum chamber.[27] Approximately 3 ft. of seam may be inspected at one time in this manner.[27]

Hydrogen-Chloride Pressure Tests

A relatively sensitive test consists of pumping hydrogen-chloride gas under 5 to 10 psi. pressure between the liner and the backing steel. The inside of the vessel is then swabbed with ammonia which produces a white cloud at the point of leakage.[25, 22] One of the disadvantages of this procedure is the necessity of removing the hydrogen chloride after the test to prevent corroding the steel. This method is very rarely used for testing liners.[68]

Hydrostatic Tests

In another test, the lined vessel is subjected to a hydrostatic pressure of about $1^1/_2$ to 2 times the working pressure.[21, 22] Back seepage will be indicated on a lime-wash coating if applied over the surface within 24 hr. after the hydrostatic test.[68] When this coating becomes dry (which may be hastened by the use of electric fans or warm air) back seepages can be noted quickly by the appearance of wet spots. The lime-wash coating acts as a blotter for the seepage and thus indicates the location of leaks or cracks.[68] Primarily the larger weld defects are revealed by this method such as centerline cracks and pinholes.[61] Fine check cracks may not be indicated by the lime-wash coating.

When this procedure is used, it is particularly im-

portant to avoid trapping water between the lining and backing plates (see also page 335-s).

Telltale Holes

Some users of spot- and seam-welded, through welded, plug-welded and strip-lined vessels are now drilling telltale or weep holes through the backing steel up to, but not through, each liner panel. These telltale holes readily disclose defects in the lining or lining welds and enable the user to make repairs promptly.[64] Others feel that it is more important to eliminate telltale holes since they permit circulation and replenishing of the corrosive medium and do not permit products of corrosion to seal off minor leaks.[60] When telltale holes are present in the backing plate to assure atmospheric pressure behind the liner the vacuum chamber test gives excellent results.[61]

Tension Tests

A tension-type of test specimen was prepared by Carpenter[25] to show the relative effect of spot-weld center spacing on the tensile load necessary to pull the stainless liner from the backing steel. The actual specimen, shown in Fig. 16, was prepared by welding suitable steel bars to both sides of a 2-in. square, spot-welded specimen. Typical test results are reported in Fig. 2.

Corrosion Tests

Special corrosion tests for applied liners ordinarily are not made since the liner materials are evaluated under the same testing conditions as solid stainless steels.† Only in a few cases have special test coupons been prepared to evaluate the effects of particular lining procedures and the behavior of the resulting specimens in particular service environments.[24]

Code Requirements

In the *Interpretations to the ASME Boiler Code,* Case 1078,[17] special emphasis is given to welding procedures and to the qualification of welded joints in pressure vessels that are lined with corrosion-resistant materials which are welded either to the plates before forming, or to the shell, heads and other parts after assembling and welding of the backing steel parts.

† These tests are discussed in another review.[11]

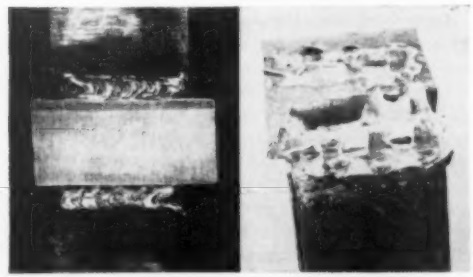


Fig. 16 Tension test specimen used in evaluation of spot-welded applied liners.[25] (Area of spot-welded specimen measured 2 x 2 in.)

Procedure Qualification Tests

Spot- and Seam-Welded Liners: The welding procedures to be used in attaching the liner panels to an existing vessel must first be qualified by the preparation of sample welds of designs and arrangements similar to those which will be used in the construction of the vessel. Moreover, the test plates should be made from materials within the chemical-composition range of the base plate, lining and electrodes (if used) that will be used in the vessel. One sample weld from each position, for each procedure to be used in the vessel, should be sectioned, polished and etched so that a clear demarcation of the fusion zone and the base steel can be observed. Visual examination of the cross section should show no lack of fusion in the fusion zone and as cracks in either the fusion zone or in the heat-affected zone.

Liners Applied by Plug Welding, Strip Welding and Through Welding and Weld-Metal Overlays: When it is intended (1) to protect portions of the base steel against corrosion by layering with weld deposits, or (2) to deposit weld metal in contact with both the base steel and a special lining sheet as in some types of attachment welds or (3) to fill-in the gap between the edges of lining sheets in contact with the base steel, the welding procedure must be qualified for each position with materials within the chemical range of base steel, lining and electrodes to be used in the construction of the vessel. The test plate arrangement is to consist of two liner strips held in contact with a base plate of not less than 3 in. wide by 6 in. long. The weld joint should be lengthwise to the plate, approximately midway between the sides and made in accordance with the procedure to be used in the construction of the vessel. The width of the gap between the edges of the liner strips should be at least $^3/_4$ in. except that, for qualification of the welding procedure for a gap between liner sheets in the vessel, it may be at least $^3/_4$ in. ($^3/_8$-in. max. gap qualifies any gap thickness and layering) or may be equal to the maximum gap to be used in the construction of the vessel, but not less than twice the lining thickness. The thickness of the backing-steel plate should be not less than $^1/_4$ in. and the thickness of the lining strips should not be less than 80% nor more than 120% of the thickness that will be used in the construction of the vessel. The test assembly must then be welded, cooled and must receive the same heat treatment (if any) as will be employed in the construction of the vessel. The weld reinforcement should be removed flush with the surface of the lining material. Two suitable longitudinal bend speci-

mens should be prepared, with the weld approximately midway between the sides, and bent with the lining in tension.

Operator Qualification Tests

Qualification tests also are required of each operator.

Radiographic Examination

Radiographic examination, when it is required, must be made of the completed weld (including the lining) when the weld is covered by a corrosion-resistant weld deposit. However, under certain conditions it is permissible to make the radiographic examination before such a weld deposit is made. This procedure is permissible when the base plate weld reinforcement is removed on the surface to be covered, leaving that surface reasonably smooth, free from undercutting and flush with the adjacent plate, and provided that (1) the weld deposit is of a nonair-hardening steel which is applied by a process that meets the bend test requirements and (2) spot radiographic examination of the joint in the lining material is made after the final corrosion-resistant weld deposit has been completed.

Radiographic examination throughout the length of all completed welds is required when vessels are lined with straight chromium stainless-steel liners and have been welded with straight chromium stainless-steel electrodes wherever the base plate weld is in contact with the stainless-steel weld. Radiographic examination is also required when the widths of such welds exceed $^1/_2$ in. of fusion to the base plate. This, of course, includes weld metal overlays of straight chromium stainless-steel material.

Complete radiographic examination is not required when austenitic stainless-steel welding rods are used for welding the straight chromium stainless-steel linings. In this case, however, spot radiographic examinations shall be made after the liner joints are welded and should include some of the joints in contact with base metal welds if radiography is required.

Many additional requirements and recommendations are also discussed in the Interpretations.[17]

A welder qualification test procedure was used at the Standard Oil Company of California for vessels to be lined by plug welding before the Code cases were written which consists of the following procedure:[51] (1) Prepare a $^1/_2$-in. thick carbon-steel plate, 6 in. square, and two panels of straight chromium stainless-steel sheet lining with three $^5/_8$- or $^{11}/_{16}$-in. holes punched or machined 3 in. apart. (2) Tack weld one sheet to the center of each side of the plate. (3) Hold the plate stationary in the vertical position and plug weld the holes in one panel and edge weld one vertical edge with a $^5/_{32}$-in. diameter 18–8 (Cr-Ni) stainless-steel electrode. (4) Hold the plate in the overhead position and weld the holes in the second panel and one edge. (5) Sandblast both sheets and examine for weld defects. (6) Test for the tightness of the welds by driving a wedge under the panels. The plugs should not pull loose from either the steel or the stainless steel liner panel. All welds showed good penetration.[51]

SERVICE FAILURES

Most failures of applied liners generally can be attributed to defects in the weldments which, in most cases, could have been prevented by good workmanship or by correct selection of materials. Many weld metal defects are quite small and may escape detection by the testing procedures through which the vessel has to pass. Certain service conditions may aggravate these small defects and, in time, cause the vessel or structure to fail. For these reasons periodic examinations are quite important during the service of the vessel.

To minimize service failures it is also highly important that correct welding procedures based on trial and test are set up for every liner installation.[57] Where these are of a routine nature, a general specification will be sufficient; however, for unusual cases each job should be considered individually by a qualified person or group and their recommendations should be followed to the letter by qualified welders.[57]

Entrapped Moisture

Moisture entrapped between the liner panel and the base plate can cause trouble in almost any type of spot-welded and lined vessel. If a vessel in which moisture has been trapped behind the liner plates which cannot escape is subsequently used at or exposed to elevated temperature any remaining moisture will flash into steam which may bulge, tear loose or even blow off the respective liner panels.[15, 18] The hydrostatic test is one of the most severe procedures which may cause moisture to seep behind the liner panels through cracks in the weld beads.* However, moisture can also accumulate by seeping behind the liner panels through cracks from a humid atmosphere, or from an air and soap suds test.[66]

The danger of moisture entrapment is particularly great when the applied lining has generous voids between it and the backing steel.[68] In spot- and seam-welded linings where the spacing is uniform and the lining is very tight to the base steel entrapment of moisture is rarely a problem.[68]

Because of the dangers of trapping moisture behind the liner panels, some manufacturers have adopted

*The following represents a typical example of the consequences of entrapped water in a strip lined vessel.[18] Great care was used to repair and seal off all cracks in a large lined vessel for refinery service. The lined vessel was subjected to several hydrostatic tests. Each time the vessel was emptied, the lining was carefully checked for seeps, which were repaired. The liner finally was made tight and put into service at elevated temperature. Several months later the vessel was shut down and it was found the lining had been practically destroyed. A good job had been done in repairing all defects, but in the process, considerable water apparently had been trapped behind the liner. When the vessel became hot, the water was converted to steam which could not escape except by tearing the liner loose.[18] An air test with soap suds would have been a better procedure.[57] Moreover, the valve on the telltale holes, if such holes had been installed, should have been opened during the start up to allow removal of the steam which formed from the entrapped water.[57]

the policy of heating every vessel to above 400° F. (205° C.) either in a stress-relieving furnace or by means of torches after testing the lining—before closing the test plugs.[18, 66] If this procedure is not followed, serious damage can be caused to the lining after the vessel is placed into service.[66] Of course, when telltale holes in the base steel behind each liner panel are left open the dangers arising from entrapped moisture are eliminated since steam, when it forms, can escape through the telltale holes.

When cracks are present in the weld or when they have occurred during corrosive service and are not immediately repaired, the extent of damage will usually become quite severe because the corrosive liquid can seep underneath the liner panel and result in accelerated corrosion such as crevice corrosion, galvanic corrosion, etc.[37] When such leaks are welded closed with the corrosive liquor left back of the liner plates subsequent heating which produces steam may cause considerable bulging of the liner plates or may even tear them loose.[60] Sometimes bulged liner panels are hammered flat; however, this generally results in further cracking in the welds and may cause cracking in welds joining adjacent liners which did not leak originally.[60] Such cracks and leaks should be repaired by heating the liner panel to over 400° F. (205° C.) to drive out all the entrapped corrosive liquid and then reweld the defective area. Sealing over defective area with a small patch of stainless steel plates is also sometimes recommended.[60]

Stress-Corrosion Cracking

In service environments which promote stress-corrosion or caustic embrittlement, stresses that are caused by the difference in the coefficients of expansion of the materials involved and by welding may result in stress-corrosion cracking when of sufficient magnitude. For example, in a plug-weld applied liner (Type 405) the presence of leaks, and a stress-corrosive condition added by the service environment, caused transgranular failure of the stainless lining.[37, 62] On the other hand, in a sulphate digester, where seepage of the sulphate solution occurred through defective welds, the presence of high residual stresses in the backing steel in contact with the corrosive solution has resulted in stress-corrosion cracking of the backing steel.[67] This vessel had not been previously stress relieved.[67]

Vessels which have been stress relieved seem to be far less susceptible to stress-corrosion cracking.[67] Thus, stress-relieving heat treatments seem to be highly advisable when vessels are to be used in contact with solutions which promote stress-corrosion.

Thermal Fatigue and Shock

The greater coefficient of expansion of austenitic stainless-steel liners may, in elevated temperature service, sometimes cause the lining sheets to be torn away from each other or from the shell. This tearing loose of the liner panels may be particularly severe in vessels which experience severe thermal fatigue cycles. To prevent this tearing it has been suggested that the liner panels be preformed to contain smooth sinusoidal curvature having two sets of parallel valleys.[44] The valleys of one set are to intersect the valleys of the other set at substantially right angles with the low points occurring at the intersections. The sheets are then attached to the vessel wall at the intersections of the valleys. The margins of adjacent sheets should overlap and the edges of the upper liner panels should be welded to the lower liner panels.[44] However, since this procedure seems rather costly, it has been rarely used in commercial installations.

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WELDING RESEARCH COUNCIL BULLETINS

The Welding Research Council has inaugurated a series of Bulletins to include reports for which space cannot be provided in the regular Welding Research Supplement. These Bulletins are furnished to the contributors and research workers of the Council and placed on sale at a nominal charge through the American Welding Society. A list of the Bulletins published to date and their prices are:

No. 1. *Steel Compositions and Specifications*, by Charles M. Parker, March 1949. Price: Fifty cents.

No. 2. *The Nature of the Arc*, by J. D. Cobine, April 1949. Price: Fifty cents.

No. 3. *Burn-Off Characteristics of Steel Welding Electrodes*, by D. C. Martin, P. J. Rieppel and C. B. Voldrich, May 1949. Price: Fifty cents.

No. 4. *Testing Pressure Vessels*, by F. G. Tatnall, and *Effect of Welding on Pressure Vessel Steels*, by A. F. Scotchbrook, L. Eriv, R. D. Stout and B. G. Johnston, February 1950. Price: Fifty cents.

No. 5. *How Plastic Deformation Influences Design and Forming of Metal Parts*, by John R. Low, Jr., and *Brittle Fracture in Mild Steel*, by J. S. Hoggart, May 1950. Price: One dollar.

No. 6. *Stress Corrosion Cracking of Stainless Steels*, by Helmer Nathorst. Part I—Practical Experiences; Part II—An Investigation of the Suitability of the U-bend Specimen, October 1950. Price: One dollar.

No. 7. *Instrumentation for the Evaluation of the Stability of the Welding Arc*, by L. P. Winsor, L. McDonald Schetky and R. A. Wyant, November 1950. Price: One dollar.

No. 8. *Tests of Columns Under Combined Thrust and Moment*, by L. S. Beedle, J. A. Ready and B. G. Johnston, December 1950. Price: One dollar.

No. 9. *Copper in Stainless Steels*, by Helmut Thielsch, August 1951. Price: One dollar.

No. 10. *Thermal Fatigue and Thermal Shock*, by Helmut Thielsch, April 1952. Price: One dollar.

No. 11. *Investigations of Effect of Fabrication Operations Upon Pressure Vessel Steels*, by S. S. Tör and Robert D. Stout, May 1952. Price: One dollar.

Fatigue Strength of Panels with Welded Angle Stiffeners

A report of an investigation to determine the life of different types of welded joints in angle stiffeners attached to plates, when subjected to many repetitions of loading

by R. Weck, Ph.D.

INTRODUCTION

THE construction and particularly the repair of ships frequently requires joints to be made in frames, beams and bulkhead stiffeners. Failures are experienced in such joints occasionally, when these are executed in the form of butt welds. These failures have the characteristic appearance of fatigue failures.

The investigation described in this report was carried out to determine the life of different types of welded joints in stiffeners when subjected to many repetitions of loading. The attachment of the stiffeners to the plating was also investigated.

The resonance method was used to carry out these fatigue tests with specimens consisting of stiffeners welded to plates with and without welded joints in the stiffeners. Most of the specimens were made in the laboratory. The joints in these specimens were made with such great care as could not normally be expected in the shipyard under conditions of production. A number of specimens, typical of present-day practice and fabricated in shipyards, were included in the series of tests.

DESCRIPTION OF TEST PIECE

The specimens, of the cross section shown in Fig. 1, consisted of plates 10 ft. long, 2 ft. wide and $^5/_{16}$ in. thick. Two angle stiffeners 6 by 3 by $^5/_{16}$ in., or in the case of the riveted specimens two channels 6 by 3 by $^5/_{16}$ in. were attached to the plates either by continuous or intermittent fillet welds or by riveting. In order to obtain a symmetrical cross section with the two principal axes of inertia parallel and normal to the plane of the plate the angles were attached opposite hand at 12 in. distance. Each specimen weighed approximately 440 lb. The neutral axis of the section was 1.85 in. above the outside surface of the plate and the moment of inertia about the principal axis parallel to the plane of the plate was 71.9 in.^{4}.

Most of the specimens had stiffeners with a welded joint of one type or another in the middle. There were no joints in any of the plates.

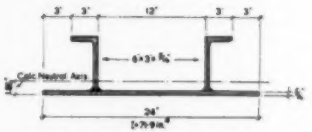


Fig. 1 Cross section of specimen

CHEMICAL COMPOSITION AND PROPERTIES OF THE MATERIAL

The specimens were constructed from mild steel to British Standard 13. The steel was obtained from the current production of a steel works which manufactures a large quantity of steel for use in shipbuilding.

The chemical composition of the plates and angle material were as follows:

	Plate, c_i	*Angle*, c_0
Phosphorus	0.033	0.013
Sulphur	0.075	0.040
Silicon	Trace	0.004
Manganese	0.460	0.620
Carbon	0.108	0.184
Copper	0.095	0.278
Nickel	0.120	0.320
Arsenic	0.030	0.032
Tin	0.018	0.030
Chromium	0.042	0.038
Molybdenum	0.025	0.040
Nitrogen	0.0035	0.0050
Aluminum	0.004 = 1.4 oz./T	0.005 = 1.8 oz./T
Alumina	0.002 = 0.4 oz./T	0.002 = 0.4 oz./T
	1.8 oz./T	2.2 oz./T

The mechanical properties of the material were as follows:

	Plate	*Angle*
Ultimate tensile strength	25.8–26.04 (tons/sq. in.)	29.8–32.4 (tons/sq. in.)
Yield stress (upper)	19.2 (tons/sq. in.)	20.4–20.8 (tons/sq. in.)
Yield stress (lower)	17.4–17.6 (tons/sq. in.)	19.7–21.2 (tons/sq. in.)
c'_e elongation (2 in. gage length)	37–38	33–39
c'_q reduction of area	62–71	62–67
Vickers hardness variation	108–129	130–149

The McQuaid-Ehn grain size was the same for both the angle and the plate material, namely, 1 to 5, mostly 2.

FABRICATION OF SPECIMENS

In order to ensure that the number of flaws in the butt welds of the stiffeners was kept to a minimum, the joints in the stiffeners were made before the stiffeners were attached to the plating. All welding was done in the downhand position.

This report was first issued to members of the British Welding Research Assn. as a confidential document in November 1950. This version is an abstract of a more complete report published by the BWRA.

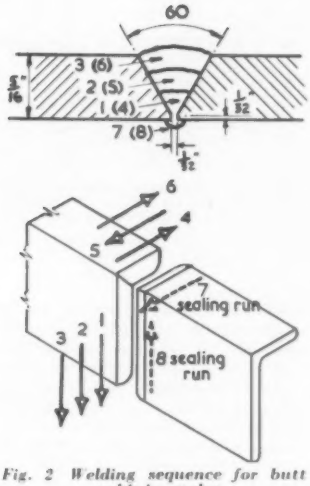


Fig. 2 Welding sequence for butt welds in angles

The ends of the angle stiffeners were chamfered in a shaping machine to a 60° Vee, with the wider part of the Vee on the outside of the angle. The gap and root face were $^1/_{32}$ in. The butt weld was made with three runs in each leg of the angle, in the sequence indicated in Fig. 2. Runs 1 and 4 were made with 10 G electrodes, the remaining runs with 8 G electrodes. The back of the angle was then chipped out to nearly half its thickness and this was filled with another run from an 8 G electrode. This left a point of poor penetration at the heel of the angle where the material is thickened by the angle fillet. In the first few specimens (Nos. C1 to C4, C11 and C12) a conical hole was made at this point after completion of the joint and this was filled with weld metal. This procedure was unsatisfactory and in later specimens (Nos. C21 to C24 and C31 to C34) the inside of the angle at the heel was chipped out at right angles to the direction of the butt weld for a distance of approximately $1^1/_2$ in. and this was then filled with a weld crossing the main butt weld at right angles. This procedure eliminated the inevitable flaws which were left at this point when using the first procedure.

The straps for the specimens in which the butt weld was reinforced by a strap were also attached before the stiffeners were welded to the plating. The fillet welds attaching the straps to the angle were stopped $^1/_2$ in. short at each side of the butt weld. Before attaching the straps the butt welds were ground flush.

The fillet welds attaching the straps were of unequal leg length and were carefully filed with a rotary file after welding to eliminate all traces of undercut and to produce a smooth contour.

The end of the butt weld in the longer leg of the angle stiffener which was welded to the plating was cut out with a saw producing a 2-in. diameter semicircular scallop, in order to avoid crossing the butt welds with the fillet welds, by means of which the stiffeners were attached to the plating.

It may be noted that very high residual and reaction stresses were undoubtedly introduced in these specimens during construction and severe plastic deformations took place during welding in the vicinity of the welds. This became visible when Lüders lines appeared in some of these specimens after they had been accidentally exposed to moisture.

Most of the stiffeners were attached by intermittent fillet welds of $^5/_{16}$-in. nominal leg length, but some specimens were attached by continuous fillet welds of $^1/_{16}$-in. nominal leg length. These continuous fillet welds, however, were not deposited by welding continuously from the center outward or from one end of the stiffener to the other, but by a step back method.

RADIOGRAPHIC EXAMINATION

The first 20 specimens were very carefully examined radiographically at the radiographic laboratory at H. M. Dockyard, Chatham. The following is quoted from the radiography report:

"*Surface Undercutting.* There was little evidence of this defect in any of the welding examined. It was nowhere more than occasional in extent and slight in nature.

"*Porosity.* This defect generally appeared as a few faint spots well distributed through the welding. Only one instance of a small localized group of spots was apparent.

"*Inclusions.* A line inclusion was evident at the root of all the fillet connections between the stiffeners and base plates. From its position relative to the weld this line inclusion appeared to be under the toe of the stiffener and was presumably anticipated, therefore, from the edge preparation and method of welding employed. In a number of intermittent fillet welds there was evidence of a small slag patch close to the end of the welding, and this should generally have been visible on the surface.

"Inclusions in the butt joints generally appeared as short faint lines at or near the root of the weld.

"*Incomplete Root Penetration or Lack of Fusion.* This defect was evident in the root of practically the whole of the fillet connections between the stiffeners and base plates, and was associated with the line inclusion at the root of the stiffeners. There was no evidence of the defect in the butt joints.

"*Cracking.* Cracks were evident in eighteen positions and were suspected in three others. In all but one position, the crack was either at or close to the end or the intermittent connection between stiffener and base plate. No cracking was revealed in the butt joints."

The inclusions at the root of the fillet connections between the stiffeners and the plates and the incomplete root penetration were undoubtedly due to the fact that the edge of the angle was not machined prior to welding. These faults were inevitable with angles having rather sharp edges.

The cracks at the ends of the intermittent fillet welds were presumably crater cracks.

When the tests with the specimens which had been radiographically examined had been concluded, the fatigue failure could in no case be related to the radiographic findings pertaining to the particular specimen.

In some of the specimens with machined butt welds the failure started from an inclusion at the heel of the angle which was inevitable with the procedure employed for these first specimens, but this flaw would not be revealed in radiographic examination because of the changing thickness of the angle at the heel. The remaining specimens tested in this series of experiments were not examined radiographically because no correlation whatsoever had been established between the fatigue failure of the first 20 specimens and the radiographic findings.

OBJECT AND SCOPE OF INVESTIGATION

The maximum stress range to which any part of a ship structure is subjected repeatedly in service is not known. There is even considerable doubt whether the cyclic component of the service stresses in a ship structure attains high enough values often enough for the possibility of fatigue failure to be considered, although failures exhibiting the characteristic appearance of fatigue fractures have been observed in ships. Since the service stresses in ships are not accurately known, the determination of the absolute endurance limits for different types of details in terms of tons per square inch, by means of S-N curves, is of little use. It is useful to know, however, in what order different types of joints will range according to their fatigue endurance. To determine this order was the object of the present investigation. For the determination of absolute values of fatigue limits, a fairly large number of tests is required. To determine the fatigue limit of only one type of joint would require fatigue tests to be carried out at least at three or four stress levels and several specimens would have to be tested at each stress level in order to arrive at a reasonable average, in view of the very considerable scatter of results which must be expected in the testing of full-scale structures and which cannot be avoided completely even in fatigue tests with small, homogeneous and polished, metal test pieces.

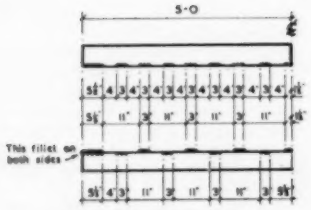


Fig. 3 (a) Arrangement of intermittent fillet welds (staggered), specimen Type B

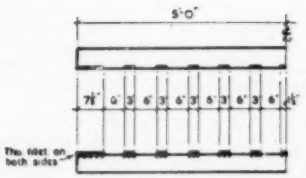


Fig. 3 (b) Arrangement of intermittent fillet welds (chain), specimens Type I and H

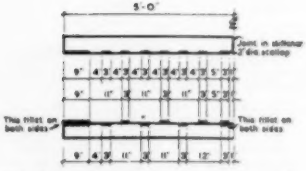


Fig. 3 (c) Arrangement of intermittent fillet welds (staggered), specimens Type C, D, E and K

In view of the limited objective of this investigation, it was hoped that tests with only four specimens of each of five different types of joints would be sufficient to establish the correct order of endurance. It was decided to test two or three of the four specimens at a stress range of ±8 tons per square inch and the remaining one or two at a lower range. The stress range of ±8 tons per square inch was chosen because it was thought that higher stresses than ±8 tons per square inch would not occur in a ship with sufficient frequency to give rise to fatigue failure.

It was envisaged at the beginning to test five different types of specimens and to extend the investigation in the light of results obtained with these specimens. The five different types of specimens were as follows:

Specimens Code Letter A. Unjointed continuous stiffeners welded to the plating with continuous fillet welds.

Specimens Code Letter B. Unjointed continuous stiffeners welded to the plating with staggered intermittent welds of 3-in. length at 7-in. centers. The arrangement of the fillet welds for these specimens is shown in Fig. 3 (*a*).

Specimens Code Letter C. Stiffeners jointed at the center by a butt weld and welded to the plating by intermittent staggered fillet welds. The reinforcement of the butt weld removed by grinding. The arrangement of the fillet welds is shown in Fig. 3c.

Specimens Code Letter D. Stiffeners joined with butt welds in the middle, the butt weld being reinforced with a rectangular strap of the dimensions shown in Fig. 4, attached with end fillet welds and side fillet welds. The fillet welds attaching the rectangular strap were dressed with a rotary file.

Specimens Code Letter E. Stiffeners joined by a butt weld in the middle, the butt weld being reinforced by a diamond-shaped strap of the shape and dimension shown in Fig. 5 attached by fillet welds all round. The fillet welds attaching the strap were dressed with a rotary file.

It was realized, of course, that the dressing of the fillet welds is not practicable in the shipyard, but it was decided, nevertheless, to dress these fillet welds in order to eliminate in this first investigation any accidental effects due to differing quality and shape of the welds.

Specimen Code Letter F. Two of the specimens of type A were unbroken after considerably more than 10,000,000 loading cycles and the third specimen lasted for a number of cycles well in excess of that obtained for any other type of specimen, so that only three specimens of Type A were actually tested. The fourth specimen which had been made was subsequently cut through the stiffener with a saw and a rectangular strap of the form and dimensions shown in Fig. 6 was attached by ordinary unmachined fillet welds to the flanges of the angle stiffener over the unwelded gap. This specimen was given the code letter F.

Specimens Code Letter G. The test with one of the specimens of Type B had to be discontinued because of a mechanical fault of the testing gear and a second specimen which had been made was not tested because the results obtained for the other two specimens were so close together and so far above the results obtained for any other specimen, with the exception of those which had the stiffeners attached by continuous fillet welds, that it was thought superfluous to test more than two specimens. The stiffeners of the remaining two specimens were again cut with a saw and the stiffeners subsequently joined again with a butt weld which was reinforced with an angle strap of the form and dimensions shown in Fig. 7. These specimens are called G1 and G2. G1, however, differed somewhat from G2. When G1 was tested it failed after a small number of cycles. The ends of the angle reinforcement, where the fatigue failure started and which had been left proud in Specimen G1 were, therefore ground away for Specimen G2, together with part of the fillet weld at this point in order to create a smooth transition between the strap and the angle stiffener.

Specimens Code Letter K. The tests with specimens F, G1 and G2 were merely exploratory, but they showed that some other type of strap would have to be designed if results were to be obtained approaching those obtained with the plain butt weld. A. T. S. Gardiner, one of the author's collaborators, suggested a strap, illustrated in Fig. 8, in which the end of the strap is placed near the neutral axis. This type of reinforcement is called the "Gardiner" strap in this report. The first specimen of this type was made from Specimen F after this had fractured.

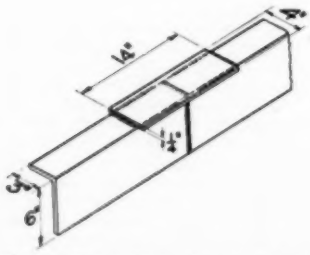


Fig. 4 Dimensions of rectangular-reinforcing strap specimens Type D

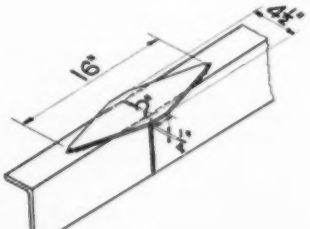


Fig. 5 Dimensions of a diamond-shaped reinforcing strap specimens Type E

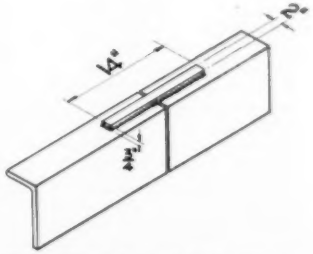


Fig. 6 Strap for unjoined stiffeners, specimen Type F

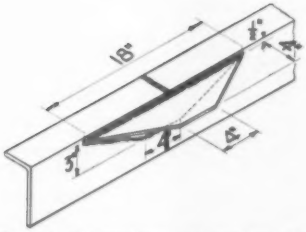


Fig. 7 Dimensions of angle-strap specimens, Type G

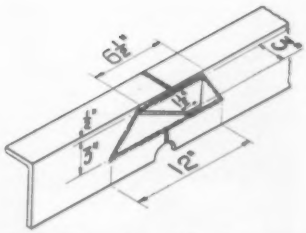


Fig. 8 Dimensions of Gardiner-strap specimens, Type K21 and K22

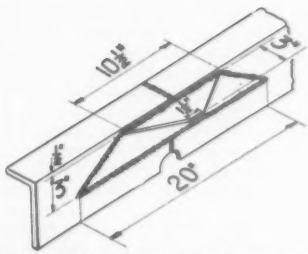


Fig. 9 Dimensions of Gardiner-strap specimens, Type K31 and K32

The broken pieces of the rectangular strap were chiselled off, the saw cut was joined with a butt weld and the strap cut from an angle was then welded with fillet welds all round onto the angle stiffener. The fillet welds were not machined. This specimen was called K1.

After this specimen had been tested the result was sufficiently encouraging for four further similar specimens to be made from virgin material. Two of these specimens, K21 and K22 had straps of the dimensions shown in Fig. 8 and the dimensions of specimens K31 and K32 are shown in Fig. 9. While the straps were actually cut from angles they could be made more quickly from flanged plate. The strap used in specimens K21 and K22 can be made by flanging a 45-degree isosceles triangle and cutting off one corner and the strap used in specimens K31 and K32 can be made from a 30-degree isosceles triangle.

Specimens C11, C12, C21 to C24, C31 and C32. The original program envisaged the testing of four machined butt-welded specimens called C1, C2, C3 and C4. This was subsequently extended by testing two additional specimens C11 and C12 with butt welds similar to those of C1 and C4, but with the reinforcement of the butt weld not removed. Six further specimens were made by using a hydrogen-controlled electrode for making the butt welds and the butt welds were actually made with a slightly differing procedure, as explained previously. Of these six specimens, four were tested with the butt welds machined. These were specimens C21 to C24. The remaining two specimens C31 and C32 were tested with the butt welds not machined.

Specimens D21 to D24, and E21 to E24. After the specimens D1 to D4 and E1 to E4 had been tested at a stress range of either ±8 tons per square inch or ±6 tons per square inch., four further specimens of each type and identical with D1 to D4 and E1 to E4, respectively, were tested under somewhat different stress conditions. These specimens are designated D21 to D24, and E21 to E24, respectively.

Specimens D1 to D4 and E1 to E4 were tested so that the stress range of ±8 tons per square inch or ± 6 tons per square inch respectively, was obtained at the point of transition between stiffener and strap, that is, at the point of maximum stress concentration. The two series of specimens D21 to D24, and E21 to E24 were tested so that the stress range at some arbitrarily chosen point at some distance away from the strap along the stiffener was equal to the stress range obtained at the identical point in the specimens with continuous unjointed stiffeners, when these were tested at a stress range of ±8 tons per square inch and ±6 tons per square inch in the center of the specimen at the point of maximum stress.

Specimens Code Letters H and I. Four specimens with continuous stiffeners were tested in which the stiffeners were attached by intermittent chain fillet welds as shown in Fig. 3(*b*). Two of these specimens, H1 and H2, had scalloped stiffeners with scallops of the form and dimension shown in Fig. 10. The other two specimens I1 and I2 had continuous stiffeners without scallops.

Specimens Code Letter L. After a fairly large number of the tests had been completed it was decided to test a number of specimens fabricated in shipyards with joints such as are current practice. Four specimens called L1 to L4 were made with stiffeners butt welded and reinforced by an angle strap fillet welded to the stiffener on the inside as shown in Fig. 11. The holes in the vertical legs of the angles are erection holes to facilitate fitting *in situ* of the bosom bar preparatory to welding. The butt welds for specimens L1 and L2 were welded in the natural V-position while in specimens L3 and L4 the butt weld and strap were both welded in the overhead position. The stiffeners were welded to the plating in the downhand position in both cases.

Specimens Code Letters O and P. Seven specimens, O1, O2, O3 and P1, P2, P3 and P4 were similar to the specimens C11 and C12, that is, the stiffeners were joined with butt welds, the reinforcement being left on. Specimens of Type O were made in one shipyard and specimens of Type P in another.

In Specimen O1 the back of the butt weld was chipped out and rewelded. Specimen O2 was also welded from both sides but slag was not removed. This specimen would contain a poor quality butt weld in comparison with Specimen O1. Specimen O3 was also welded from both sides but only the slag was removed prior to welding from the back, the weld itself not being chipped out. This specimen should, therefore, be of intermediate quality between O1 and O2.

The two specimens P1 and P2 were

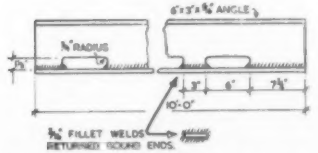


Fig. 10 Dimensions and spacings of scallops in stiffeners of specimen Type H

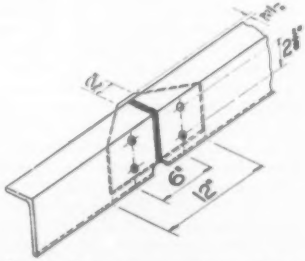


Fig. 11 Dimensions and form of strap for specimens L1 to L4

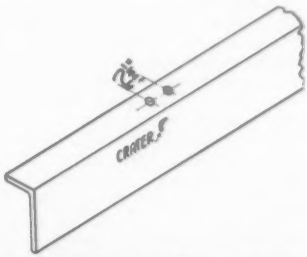


Fig. 12 Perforated stiffeners of specimens M1 and M2

intended to represent good shipyard practice, while in the specimens P3 and P4 it was tried to incorporate in the butt weld the most common fault, namely, some lack of fusion, particularly at the heel of the angle. The intermittent welding of the stiffeners to the plating was done downhand. For a distance of 18 in. on both sides of the butt weld the stiffeners were left unwelded until the butt was completed.

Specimens H11 to H14. It was believed that the cracks which were observed in specimens H1 and H2 at 45 degrees to the neutral axis, starting from the curved edge of the scallop, might be due to the fact that the flame cutting started hair cracks at these edges which propagated under fatigue loading or that the material round these edges was decarbonized and softened.

Since scallops are not generally flame cut in shipyards but punched, it was decided to have four further specimens H11 to H14 made in a shipyard with scalloped stiffeners identical to those in H1 and H2 but with the difference that the scallops in these stiffeners were punched.

Specimens Code Letter M. Finally, in order to determine the effect of holes on the fatigue strength of unjointed stiffeners, two specimens were made, each having two holes $^{13}/_{16}$ in. diameter, at $2^1/_2$-in. centers in the center of the flange of the stiffeners, as is shown in Fig. 12. These two specimens are called M1 and M2.

Riveted Specimens Code Letter N. Four riveted specimens N1 to N4 were also tested. These had continuous unjoined 6- by 3-in. channel stiffeners riveted to the plating. Four riveted specimens with cut stiffeners joined by a riveted angle strap ($^3/_4$ in. diameter: rivets at 7 diameters pitch) were also available, but these could not be tested by the resonance method for reasons which will be explained further on in this report.

TESTING PROCEDURE

All specimens were tested as beams in bending by the resonance vibration which has been described in detail in a previous report.*

With this testing method the specimen forms the spring in a mass spring system which is excited near its natural frequency. The system is excited by a mechanical out-of-balance exciter which consists essentially of two unbalanced masses rotating in opposite directions. The testing force proper is derived from the inertia of the specimen and vibrating masses; the out-of-balance force applied to the specimen is small in comparison with the inertia force of the system and only serves to maintain the vibration which, without continuous excitation, would rapidly die out in consequence of damping.

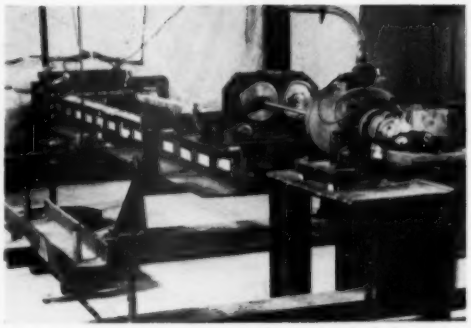


Fig. 13 Specimen set up for test

In order to keep the center of the specimens, where the joints were located, free from all attachments, the exciter was attached at one end. A balancing mass was attached to the specimen at the other end for the sake of symmetry.

The specimens were supported at the nodal points. The position of the nodal points and the natural frequency were found by calculation. The actual natural frequency of the specimen was 4300 cycles per minute and this agreed very closely with the calculated natural frequency. All tests were carried out slightly below this frequency and approximately four hours were required to run up one million loading cycles.

The calculated position of the nodal points, approximately 18 in. from the ends of the specimen, were very close to the actual nodes. Each specimen was supported in two frames placed at the nodal points. The frames were carried in bearings which were bolted to the floor. The trunnions of the frames were arranged at the level of the neutral axis of the specimen so that the frames were free to pivot without imposing any restraint when the specimen executed bending vibrations. A specimen set up for testing is shown in Fig. 13.

Extensive strain measurements were carried out for one pilot specimen with electric resistance strain gages and a cathode-ray oscillograph. The state of stress in the specimen and the corresponding deflections were determined for three different testing speeds, all very near 4300 r.p.m., which gave maximum deflections at the center of the specimen of 0.1, 0.115 and 0.15 in. respectively. The deflection was measured relative to the nodes and is, therefore, the deflection of the length of the specimen between the nodes, that is, over approximately seven feet. In order to obtain the deflection over the entire 10-ft. length, the deflection at the free ends must be added since these ends deflect upward when the center of the specimen deflects downwards.

In consequence of the fact that the loading of the specimen is due to its own inertia, the resulting state of stress is rather complex. The loading is distributed over the whole of the specimen and the load at any point is equal to the element of mass at that point multiplied by the amplitude of vibration at that point and the square of the circular frequency. Consideration of the loading at any cross section shows that when the whole specimen, considered as a beam spanning between the nodes, deflects downward, the plate, considered as spanning between the two stiffeners, must deflect upward in the center. Because of this transverse bending of the plate in addition to the longitudinal bending, the stresses in the plate must be biaxial, as they would be, in fact, if the plate were part of a ship's hull subjected to water pressure.

The stress distribution at the central cross section was obtained from strain measurements with electric resistance strain gages and a cathode ray oscillograph for three different testing speeds producing central amplitudes of 0.1, 0.115 and 0.15 in., respectively. The distribution of longitudinal and transverse stress for a central amplitude of 0.115 in. is given in Figs. 14 and 15. It will be observed from these diagrams that the maximum longitudinal bending stress occurs at the heel of the angle and falls off rapidly from there toward the toe. The distribution of bending stress in the vertical leg of the angle is linear as expected and the point of zero stress coincides approximately with the calculated neutral axis of the cross section. Each of the numerical values given in the diagrams has been obtained from strain measurements in the longitudinal and transverse direction of the specimen. That is, at each point marked, two strain gages were attached to the specimen, one in the direction of the axis of the specimen and one at right angles to the axis. The longitudinal and transverse stresses which are plotted in the diagrams were calculated from the strain measurements on the assumption that these are the directions of principal stresses, and that the state of stress is biaxial.

The distribution of longitudinal stress in the plate is not quite uniform. On the

* A. L. Percival and R. Week, "Fatigue Tests by the Resonance Vibration Method on Four Welded H-Beams." First interim report, FE.8 Committee on the Behaviour of Welded Structures under Dynamic Loading, British Welding Research Assn., January 1947.

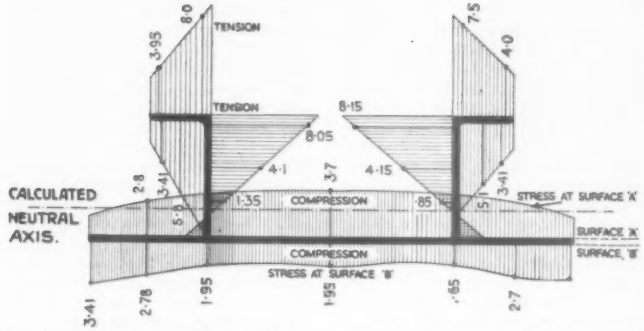


Fig. 14 Distribution of longitudinal stress (tons per square inch) at central cross section for 0.115-in. central amplitude

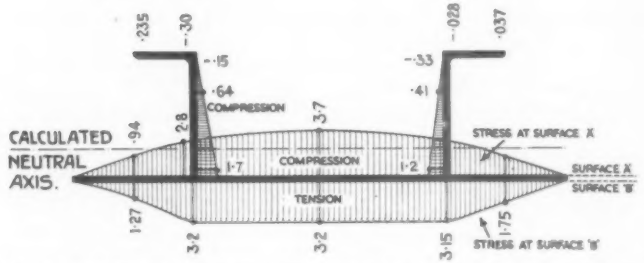


Fig. 15 Distribution of transverse stress (tons per square inch) at central cross section for 0.115-in. central amplitude

inside surface (surface A) the stress is actually larger at the center of the specimen than at the edges, and on the outside surface (surface B) the stress is larger at the edges than at the center. This is rather paradoxical considering that the inside surface of the plate is, of course, nearer to the neutral axis than the outside surface, so that one would expect the stress at the outside surface to be slightly larger than the stress at the inside surface. The reason for this apparent paradox must be seen in a longitudinal bending moment acting in the plate alone and which is superimposed on the bending moment of the specimen as a whole. Consider the instant when the specimen has reached its maximum upward deflection, when the stress in the angles is tension and the stress in the plate is compression. The stress on the outside surface should then be slightly larger than the stress on the inside surface. In consequence of the transverse bending of the plate, however, the curvature of the centerline of the plate must be somewhat smaller than the curvature of the neutral axis of the specimen as a whole. The reduction in the longitudinal curvature of the plate must be produced by a bending moment in the plate which results in compressive stresses on the inside surface and tensile stresses of equal magnitude on the outside surface. Hence the compressive bending stress in the plate, due to the bending of the specimen, as a whole, is augmented on the inside surface and reduced on the outside surface.

There are only small transverse stresses in the angles, but the transverse bending stresses in the plate may reach values of sufficient magnitude to produce fatigue failure along the continuous fillet weld attaching stiffeners to plating. It must be borne in mind that the stresses plotted in these diagrams are reached only momentarily at the extreme amplitude of deflection and that these stresses completely revert to zero during the next quarter cycle and then build up to exactly the same numerical values of opposite sign in the next quarter cycle.

The longitudinal stress was measured at the point where it reaches its maximum for each cross section, that is, at the heel of the angle all along the specimen and the results of these measurements together with the deflections of the specimen are plotted in Fig. 16. From these diagrams it is evident that the maximum stress in the whole of the specimen occurs at the heel of the angle in the central cross section and it is this stress value upon which all the fatigue data given in this report are based. It can be seen from Fig. 16 that the stress curves, which are of the same shape as the bending moment curves, since the modulus of section of the specimens is constant for the entire length, have a point of inflection at the nodes. The shear stress at these points is therefore a maximum, although there is, of course, no vertical reaction transmitted to the foundations other than that from the dead weight of the specimen. In considering Fig. 16, it must be remembered that the deflection is equal upward and downward from the neutral position and that the stress values at any point of the specimen vary between equal, positive and negative limits. The fatigue range determined in these tests is the alternating bending fatigue range as distinguished from the basic tensile bending fatigue range which is obtained in tests between zero and a positive maximum stress.

The use of the resonance method for these tests involves a certain difficulty in establishing a sound basis of comparision between specimens with continuous or butt-welded stiffeners on the one hand and specimens with stiffeners in which the butt joint was reinforced by a strap of one kind or another, on the other hand. The strap produces a local change in stiffness and a small change in mass. Both these changes will have a slight effect on the natural frequency, a more pronounced effect on the amplitude of vibration and a very considerable effect on the state of stress in the specimen. It would obviously be incorrect to base the comparison between a specimen with continuous stiffeners and a specimen with strapped stiffeners on equal stress range at the center of the specimen. It is obvious that a much higher load would be re-

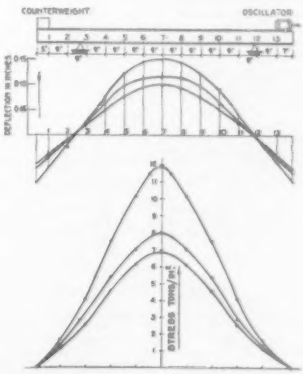


Fig. 16 Amplitudes and stresses along test piece (maximum stress values, at corner of angle, shown for each cross section)

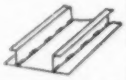
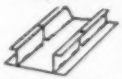
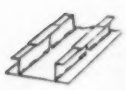
quired to produce a certain stress at the center of the strapped specimen than at the center of an unstrapped specimen. The two tests would, therefore, be carried out at very different loads and comparison of the number of cycles to failure would be misleading. A more rational basis of comparison can be established by testing the strapped specimen so that the stress range produced at the point of maximum stress concentration is the same as that in the center of the specimen with continuous stiffeners. The test load will then be somewhat smaller for the strapped specimens than it is for the continuous specimens.

A third possibility is to take some arbitrary point along the stiffener at some distance from the strap and to carry out all tests at a stress range at this particular point of the same magnitude as the stress range at the identical point in a specimen with continuous stiffeners when tested at a range of maximum stress in the middle of, say, ±8 tons per square inch or ±6 tons per square inch. The curves for the stress distribution in the continuous specimen and in the strapped specimen will not perfectly coincide, even outside the strap. The difference will be only slight, however, and therefore, the inertia loading for the two specimens, one with continuous stiffeners and one with strapped stiffeners, will be almost identical.

The tests with the specimens having diamond-shaped straps and rectangular straps were carried out in both ways. One set of four specimens was tested by maintaining the stress at the point of stress concentration at the same value as the maximum stress in the continuous specimens. Another four specimens were tested by keeping the stress at a point 16 in. away from the center at a value equal to that measured at a point 16 in. away from the center in the specimen with continuous stiffeners. All the other strapped specimens such as those with the angle strap and the Gardiner strap (specimens G and K) and the specimens which were fabricated in the shipyard (specimens L and M) were tested by maintaining a definite constant stress range 16 in. away from the center of the specimen, this stress range being equal to that obtaining at the same place in the specimen with continuous stiffeners.

It is important in fatigue tests that the stress range should remain constant during the entire duration of the test and that the test should stop immediately after the crack has developed. The amplitude control device, described in detail in the first interim report was used to maintain constant amplitude and hence constant stress range and has proved entirely satis-

Table 1

Type of Specimen	Specimen No.	Stress Range Tons/sq. in.	Number of Cycles to Failure	Location to Failure	Remarks
Continuous stiffener continuous fillets	A1	±8 ±9	11,601,740 * 1,136,360	Along undercut of continued fillet weld	Failure after further 1,136,350 cycles at ±9 tons/in.²
	A2	±8	6,508,000	Ditto	
	A3	±7 ±8	17,254,000 * 11,254,000	Ditto	Failure after further 11,254,300 cycles at ±8 tons/in²
Continuous stiffener intermittent staggered fillets 	B1	±8	3,835,340	Transverse cracks starting from end of intermittent fillet welds at approx. 12 in. distance from centre	
	B2	±8	4,717,940		
Stiffeners with butt-welds machined ordinary electrode 	C1	±8	584,180	Through centre of butt weld starting from weld flaw at heel of angle	
	C2	±8	902,500		
	C3	±7	2,941,200		
	C4	±6	1,707,520		
Buttwelds unmachined ordinary electrode	C11	±8	573,000	Through centre of butt weld	
	C12	±8	1,034,620		
Buttwelds machined hydrogen controlled electrode	C21	±8	1,495,560	Outside butt weld	
	C22	±8	691,240	Through stray flash 10 in. away from weld	
	C23	±8	1,567,580 + 980,840	Through angle near weld	Specimen C23 failed in the stiffener after 1,567,580 cycles, was repaired and endured another 980,840 cycles when it failed near the butt weld
	C24	±8	1,056,180	Failure in plate near scallop	
Buttwelds unmachined hydrogen controlled electrode	C31	±8	1,118,560	Along undercut of butt weld	
	C32	±8	2,734,140	At end of transverse sealing run	
Stiffeners with butt-welds reinforced by rectangular strap 	D1	±8†	389,760	At end of fillet weld connecting strap	
	D2	±8†	470,000		
	D3	±6†	3,740,780 * * + 2,953,380	At edge of strap	Further 2,953,380 cycles for crack to travel full width of stiffener
	D4	±6†	7,620,140	Ditto	Fracture in both stiffeners
	D11	±8††	379,340	At end of fillet weld connecting strap	
	D12	±8††	155,280		
	D13	±6††	338,320		
	D14	±6††	777,800		

* Unbroken.
* * Crack detected.
† Actual stress measured at point of stress concentration.
†† Nominal stress of continuous specimen, comparison established at point outside strap.

factory. This amplitude control device also serves to stop the test as soon as a fatigue crack develops.

As soon as a crack develops the natural frequency of the specimen changes. This means that the motor speed will be nearer to or further away from the new natural frequency and hence the amplitude of vibration will be either larger or smaller than the amplitude of vibration prior to the development of the crack. The amplitude control device will try to restore the original amplitude by speeding up or slowing down the motor. The total range of speed variation permitted by the amplitude control device is, however, much smaller than that which would be required to restore the original amplitude of the uncracked specimen. Any change in motor speed more than 5% either way will automatically shut the whole testing plant down. Usually at the end of a test the motor switches itself off even before the crack is visible to the naked eye and usually several thousand further cycles are required to make the crack visible; that is, in order to make the crack visible the plant has to be started up again for a very short time and the speed of the motor has to be continuously changed to follow the natural frequency of the specimen which keeps changing as the crack propagates.

A number of specimens was made in which the stiffeners were channels riveted to the plating; the channels were cut in the center of the specimen and a joint was made by means of a riveted angle strap. When the first of these specimens was tested, it was found that the riveted strap absorbed so much energy—this becomes evident by the very rapid heating up of the strap and the rivets—that the amplitude of vibration and consequently the stress range which could be produced with the available power was not large enough, that is, the maximum stress which could be produced with the available motor was much smaller than the stress range at which the tests of the welded specimens had been carried out. These riveted specimens will be tested later when a larger motor is available, but this interim result is interesting because it shows that the damping in riveted structures is very much higher than in welded structures.

It is conceivable that these riveted specimens would not have failed by developing fatigue cracks similar to the welded specimens, but that failure might have occurred fairly rapidly by the rivets working loose, in which case, of course, the structure would have lost its stiffness and could not have been vibrated at all. It was evident from the rapid heating taking place in the strap that rivet slip occurred even under the low stresses applied. The natural frequency of these riveted specimens was approximately 15 cycles per second lower than that of the welded specimens. It would be quite unjustified to conclude from this that riveted structures are less liable to fatigue failure than welded structures. Such experimental evidence on the fatigue strength of riveted structures as there is indicates that the fatigue strength of riveted joints is not higher than that of welded joints and may be inferior to that of butt-welded joints.

DISCUSSION OF RESULTS

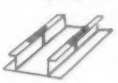
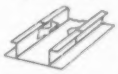
Altogether 66 specimens were tested, of which 21 had been made in shipyards, including the four riveted specimens. The test results are summarized in Tables 1 to 3. A summary of averages is given in Table 4. When these test results are examined it will be observed that sometimes a considerable difference has been obtained in the number of cycles to failure for similar specimens tested at the same stress range. In some cases a shorter life has been obtaind for a specimen tested at a lower stress range than for a similar specimen tested at a higher stress range as, for instance, in the case of C3 and C4. Both these phenomena are not unusual in fatigue tests and it is obvious that they make interpretation of the test results somewhat difficult if only a small number of specimens of each type is tested. Nevertheless, a number of interesting and important facts have emerged quite clearly in this investigation.

Specimens Without Joints in Stiffeners. Of the specimens without joints in the stiffeners, those of Type A with a continuous fillet welds are undoubtedly superior to any of the other welded specimens tested.

All three specimens of Type A failed in the same manner, by developing fatigue cracks in the longitudinal direction of the specimen along the undercut of the fillet weld. These cracks are caused by the transverse bending stress in the plate.

The riveted specimens with continuous channel stiffeners, N2 and N3, lasted even longer. In both these specimens fracture occurred at the point of maximum bending stress in the center of one of the

Table 2

Type of Specimen	Specimen No.	Stress Range Tons/sq. in.	Number of Cycles to Failure	Location of Failure
Stiffeners with butt-welds reinforced by diamond shaped strap	E1	±8†	850,460	At end of fillet weld connecting strap
	E2	±8†	669,780	
	E3	±6†	19,982,300	At point where edge of strap crosses edge of flange
	E4	±6† ±7	29,202,840 * + 6,333,480	
	E11	±8††	2,108,100	At end of fillet and at cross-over point
	E12	±8††	2,214,920	At end of fillet in one stiffener at cross-over point in other stiffener
	E13	±6††	18,132,680	In plate and stiffener starting from intermittent fillet weld
	E14	±6††	4,454,440	Centre of strap and flange
Stiffeners without butt-welds, gap spanned by strap 	F	±8 (at centre of strap)	46,620 (beginning of crack) 145,880 (fracture through strap complete)	Centre of strap
Stiffeners with butt-welds reinforced by tapered angle straps	G1	±6† ±8†	87,280	End of strap
	G2	±8†	270,240	Ditto
Stiffeners with butt-welds reinforced by Gardiner straps 	K1	±8††	757,110	Along undercut of fillet weld connecting strap
	K11	±8††	408,460	
	K12	±8††	882,180	Ditto
	K21	±8††	687,380	
	K22	±8††	1,384,740	
Continuous stiffeners intermittent chain weld	I1	±8	1,195,540	Along undercut of intermittent fillet welds
	I2	±8	2,793,400	Ditto

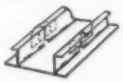
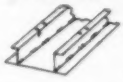
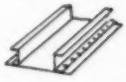
* Unbroken.
† Actual stress measured at point of stress concentration
†† Nominal stress of continuous specimen, comparison established at point outside strap.

channel stiffeners. These two riveted specimens were undoubtedly better then the welded specimens of Type A and the reason for the better behavior must be seen in the absence of the stress concentrations caused by the longitudinal fillet welds. It is possible that in these riveted specimens fatigue cracks had started from the rivet holes before the fracture in the channels developed, but no such cracks could be discovered by visual inspection.

The other two riveted specimens, N1 and N4, had a very much shorter life. One of the two channels of Specimen N1 was badly pitted by corrosion and it was this channel which failed first. The failure of Specimen N1 took place under one of the supporting frames where the specimen was held down and there was evidence of very severe fretting at this point. It is, of course, well known that severe fretting may give rise to premature fatigue failure. The specimen N4 was subsequently repaired by welding the crack and was tested again at ±8.5 tons per square inch, and it failed after a further 709,060 cycles at exactly the same spot. It must be borne in mind that these failures took place at a point where the stress is really quite low, approximately ±3 tons per square inch.

One of the surprising results in this investigation was the marked superiority

Table 3

Type of Specimen	Specimen No.	Stress[1] Range Tons/sq. in.	Number of Cycles to Failure	Location of Failure	Remarks
Continuous scalloped stiffeners chainwelded	H1	±8	1,451,050	Numerous cracks resulting in almost complete disintegration of specimens	
	H2	±8	1,568,760	Ditto	
Continuous scalloped chainwelded scallops punched			**SPECIMENS MADE IN SHIPYARDS**		
	H11	±8	1,161,590		
	H12	±8	1,138,680	Along undercut of fillet welds and at toe of return fillets	
	H13	±8	1,324,560		
	H14	±8	973,380	Broke in angle as well	
Butt weld and strap 	L1	±8††	242,540		
	L2	±8††	313,220	At end of strap through toe of fillet weld and also in the buttweld of L_1	
	L3	±8††	378,140		
	L4	±8††	617,900		
Continuous stiffeners with two holes 	H1	±8††	513,080	Through crater and hole	
	H2	±8††	401,900	Through hole	
Continuous riveted channel stiffeners 	N1	±8	2,611,900	Failed in badly corroded channel	Specimen N4 repaired by welding up crack. After 709,060 cycles failure in same place
	N2	±8	19,914,760 *	Fracture in channel	
	N2	±9	1,035,500	Ditto	
	N3	±8	25,303,860 *	Ditto	
	N3	±8.5	1,486,680	Ditto	
	N4	±8.5	1,974,920	Fracture under supporting frame in consequence of fretting	
	N4	±8.5	709,060		
Butt welds made in Shipyard "X." Reinforcement left on.	O1	±8	1,747,800		
	O2	±8	906,320	Through butt weld in all cases	
	O3	±8	1,188,560		
Butt welds made in Shipyard "Y." Reinforcement left on.	P1	±8	711,320	Failure along undercut of butt weld	
	P2	±8	439,000	Ditto	
	P3	±8	505,040	Ditto	
	P4	±8	341,840	Ditto	

* Unbroken.

†† Nominal stress of continuous specimen, comparison established at point outside strap.

Table 4—Averages of Test Results at ±8 Tons per Square Inch

Type of specimen	*No. of specimens tested*	*No. of specimens averaged*	*Average number of cycles*
Continuous stiffeners			
A, Continuous fillets	3	3	9,787,910+
B, Staggered fillets	2	2	4,276,640
I, Chain fillets	2	2	1,994,470
H1H2, Scalloped, flame cut	2	2	1,509,900
H11H14, Scalloped, punched	4	4	1,149,550
M, Riveted channel	4	2	22,609,310+
M, Perforated	2	2	457,490
Butt Welded			
C1C2, Machined	2	2	743,340
C11C12, Unmachined	2	2	803,810
C21C24, Hydrogen-controlled electrode	4	3	1,700,050
C31C32, Hydrogen-controlled electrode, unmachined	2	2	1,926,350
O, Shipyard "X"	3	3	1,280,890
P1P2, Shipyard "Y"	2	2	575,160
P3P4, Shipyard "Y"	2	2	423,440
P1-P4, Shipyard "Y"	4	4	499,300
Strapped Butts			
D1D2, Rectangular strap	2	2	429,880
D11D12, Rectangular strap	2	2	267,310
E1E2, Diamond strap	2	2	265,120
E11E12, Diamond strap	2	2	2,161,510
K11K12, Gardiner strap	2	2	645,320
K21K22, Gardiner strap	2	2	1,036,060
L, Shipyard strap	4	4	387,950

of the specimens welded with intermittent staggered fillet welds over those welded with intermittent chain fillet welds. Both types of specimens are, however, inferior to the specimens of Type A. In the case of specimens Type B, the failure started as a transverse crack in the plating, starting from one end of one of the intermittent fillet welds. It is to be noted that this type of crack never developed in the center of the specimens where the longitudinal bending stress which causes it is largest, but at some distance away from the center where the intermittent fillet welds would be subjected to direct stress and shear.

The failures in the specimens welded with intermittent chain fillet welds were entirely different. There the fatigue cracks developed along the undercut of the fillet welds. These cracks were similar to those experienced in specimens of Type A. It is difficult to account for this difference in behavior of specimens Type I and specimens Type B. Specimens Type B failed in consequence of the longitudinal bending stress, and it is conceivable that the concentration of fillet welds on both sides when chain welding is used as in specimens of Type I produces such a severe change in stiffness in the transverse direction in comparison with the specimens of type B and such severe stress concentrations in comparsion with specimens of Type A, that failure takes place in these specimens in consequence of transverse bending, very much earlier than those of Type B or Type A.

When the stiffeners are scalloped the life is reduced even further.

The mode of failure of these specimens H1 and H2 was very interesting. They developed so many cracks in different places that one could speak almost of complete disintegration. The cracks were of three types. One type of crack occurred along the undercut of the return fillet attaching the prongs of the stiffeners. The second type of crack is similar to that experienced with the specimens Type I and follows the undercut of the intermittent fillet weld. The third type of crack shown in Fig. 17 started in the circular part of the scallop and progressed approximately under 45 degrees toward the center of the stiffener roughly in the direction of the principal stress. These cracks only occur, however, near the supports of the specimen, that is, at the points where the shear is a maximum, while the longitudinal bending stress is fairly small. At the points of maximum shear, however, the principal stresses at the neutral axis under 45 degrees to the axis of the specimen are a maximum in any case, even if there is no scallop. If there are scallops, stress concentrations will occur near the neutral axis under 45 degrees and these will give rise to this type of crack. Whether these cracks are to be expected in a ship depends on the position of the neutral axis in a large panel with many stiffeners and on the magnitude of the reactions at the ends of stiffeners.

Four specimens of exactly the same type, H11 to H14, were made in a shipyard by punching the stiffeners and when these specimens were tested none of them developed this particular type of crack. The average life of these specimens, however, was somewhat less than the life of specimens H1 and H2 and is actually the lowest figure which has been found in any of the specimens without joints. The absence of the cracks under 45 degrees in these specimens is remarkable. This may be due to the work hardening of the punched edges, while the flame-cut edges are presumably softened and decarburized and therefore offer less resistance to fatigue than punched edges.

From the results obtained with the scalloped stiffeners, it does not appear that, in its present form, this type of construction gives the highest fatigue strength, and it would undoubtedly be worth while to investigate the stress distribution in stiffeners made with scallops of different form in order to see whether there is a type of scallop which will give a more favorable stress distribution.

Apart from the scalloping, the return fillets round the ends, whatever other advantages they may have, are a disadvantage from the point of view of fatigue. It is a well known fact, which has also been observed in other investigations, that such return fillets are likely to lower the fatigue strength of the component if they are normal to the direction of the larger stress. One of the reasons for this

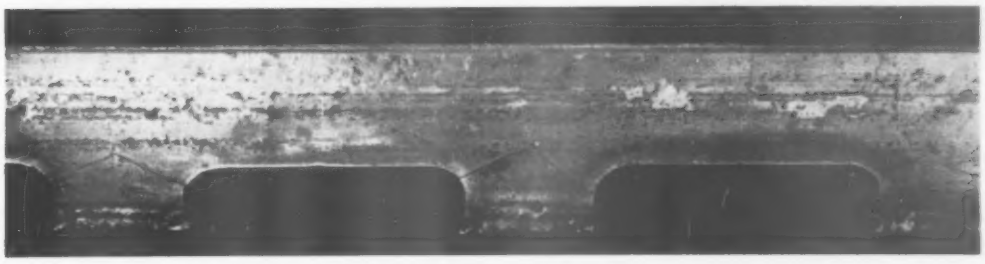


Fig. 17 Cracks through prongs in stiffener. Specimen type H

may be that there is a tendency at such return fillets to pile on weld metal. The results might be better if it were practicable to make these return fillets continuously with the intermittent fillets proper without stopping and starting.

Stiffeners with Butt Welds. The first four specimens with machined butt welds, C1 to C4, failed through the center of the butt weld. When the reinforcement was left on as in specimens C11 and C12, the failure still went through the center of the butt weld.

Specimens C21 to C24 were welded with a hydrogen-controlled electrode of which it was known that all-weld-metal specimens had given a fatigue strength at least 50% in excess of that normally to be expected from ordinary electrodes. All these specimens broke outside the butt weld. The failure of Specimen C21, which was similar to that of Specimen C23, occurred in the vicinity of the weld. Specimen C23 failed in consequence of fretting similarly as Specimen N4 had failed under one of the supporting frames. It was repaired and then a crack similar to that observed in Specimen C21 was observed near the butt weld in addition to a second fracture under the supporting frame where the repair had been effected. Specimen C24 did not fail in the stiffener at all, but fractured along the undercut of the return fillet weld in way of the central scallop. Specimen C22 failed through a stray flash 10 in. away from the weld. This fracture is shown in Fig. 18. If the result for specimen C22 is ignored, which is justified because the failure in this case was definitely due to the accidental flash, and if the total life of specimen C23 is reckoned from the time of starting the test until the fracture in the vicinity of the butt weld appeared, which is justified because the first failure was due to fretting, we obtain an average life for these specimens at a stress of ± 8 tons per square inch, considerably more than that obtained for specimens C1 to C4 with which these specimens can be compared.

Fig. 18 Crack in specimen C22 starting from stray flash

In most previous investigations it has been shown that removal of the reinforcement increases the fatigue strength of butt welds. The present series of tests have not given the same results. In both series of tests C1 to C4, C11 and C12, and C21 to C27, the average number of cycles for the ground butt welds was smaller than that obtained for the butt welds with the reinforcement left on.

This may be due to one of two circumstances or both. In the first place the superiority of machined butt welds has been established for butt welds in plates and it is possible that the difficulties inherent in the butt welding of rolled sections always result in certain inevitable flaws being incorporated in the welds, and that machining only increases the fatigue strength of butt welds if they are inherently of very good quality. The other possibility is that the improvement cannot be realized by grinding as distinct from machining. It is known that grinding marks lower the fatigue strength of metal specimens and it is possible that any improvement that might have been realized by removing the reinforcement has been nullified by the effects of grinding.

The fact that none of the specimens C21 to C24 broke in the butt weld and two of them broke at some small distance from the butt welds, seems to suggest that the heating cycle in consequence of welding to which the material at some distance from the weld is subjected has some effect on the parent metal at this distance, weakening it under fatigue conditions. Other investigators also have found that butt welds could be made which were apparently stronger than the parent metal in that fatigue failure did not take place in the butt weld but at some small distance from it, but that, nevertheless, the fatigue strength of the welded specimen was lower than that of the unwelded specimen, which is the case also for the present tests as is evident when the results for C21 and C23 are compared with any of the results obtained for continuous unwelded stiffeners.

It now remains for the butt-welded specimens made in shipyards to be compared with those made in the laboratory. Specimens O1 to O3, which were supposed to be of different quality, did show that there is a difference between O1 and the other two. There is, however, no significant difference between these last two; in fact the figures for the number of cycles to failure are in the reverse order to that which was to be expected, because O3 was supposed to be a butt weld of worse quality than O2. Considering specimen O1 alone, this is very much superior to the first series of butt welds made in the laboratory and compares well with those specimens which had been made in the laboratory with a hydrogen controlled electrode. Even the average of these three tests is better than that obtained for the first series of laboratory-made specimens and considering that two of the specimens incorporated intentionally bad welds, this average does not compare unfavorably even with the machined butt welds made with hydrogen-controlled electrodes.

The four other specimens P1 to P4 made in a different shipyard are quite evidently not nearly as good. The fact that there should be such a difference in the life of butt-welded specimens made in different shipyards is difficult to explain. It could be that the particular combination of parent metal and weld metal in specimens of Type P gave rise to micro-cracks in the transition zone between weld metal and parent metal, which made this zone a plane of weakness.

It is interesting to compare the effect of a butt weld on the fatigue strength of these specimens with the effect of drilled holes. Two specimens called M1 and M2, supplied by another shipyard, were continuous unjointed stiffeners with two plain holes. In both cases the failure started from the edge of the hole. If the figures are taken to represent the fatigue strength of stiffeners in riveted ships, they indicate that even a bad butt weld does not necessarily reduce the fatigue life of stiffeners to below the limit that would be normally expected in riveted stiffeners.

Specimens Reinforced with Straps. The results obtained with the specimens having rectangular- and diamond-shaped straps were disappointing in view of the very great care with which the fillet welds connecting these straps had been machined

The series of tests D and E showed that the diamond-shaped strap is much better than the rectangular-shaped strap, which is in agreement with the results of other investigations. In order to compare the results of these tests with those obtained for butt welds, only D11 and D14 and E11 to E14 can be considered to establish a true comparison. The rectangular strap is seen to be no reinforcement under fatigue conditions, because all four tests with specimens D11 to D14 gave results inferior to those obtained with butt welds, including those obtained for Specimens P which were the lowest figures for butt welds of the whole series. The diamond-shaped strap, on the other hand, provided this is as carefully filed as those of specimens E11 to E14 were, is seen to be a very effective reinforcement, especially of butt welds which are not of very high quality.

It was obvious, however, from the beginning of this investigation that straps which would require to be so carefully machined could not possibly be adopted as a practical means of reinforcing butt

welds in shipyards. It was necessary, therefore, to investigate other possibilities of reinforcing butt welds or of making joints in stiffeners.

The specimens of types K21 and K22 which had a more pointed strap are somewhat better than those with 45-degree straps and this type of strap can be considered to be an effective reinforcement of bad butt welds. Good butt welds, however, such as those made with hydrogen-controlled electrodes, are not likely to be improved by putting straps on even if they are of this type. The Gardiner strap compares favorably with present practice in shipyards which is represented by the specimens L1 to L4. These straps cannot be considered as an effective reinforcement even for the worst type of butt weld.

CONCLUSIONS

The following conclusions may be drawn from the present limited series of tests:

1. The fatigue strength of unjointed welded stiffeners is highest when the stiffeners are welded on by means of continuous fillet welds.

2. If intermittent welding is used, staggered fillet welding is preferable to chain fillet welding.

3. Scalloping of the stiffeners, at least when the same form of scallop is used as in these tests, is liable to decrease the life of stiffeners considerably in comparison with stiffeners welded on by intermittent staggered fillet welds, and the scallops will reduce the fatigue strength somewhat even in comparison with stiffeners welded on by chain fillet weldings.

4. The most dangerous points at which fatigue failures are to be expected in unjointed welded stiffeners are the ends of intermittent fillet welds, the undercut along fillet welds connecting stiffeners to plating and, in the case of scalloped stiffeners, the return fillets.

5. In the case of scalloped stiffeners the fatigue strength of punched stiffeners is slightly lower than that of gas-cut stiffeners subsequently dressed, but in the latter case, with the present form of scallop fatigue cracks may start under 45 degrees to the axis of the stiffeners starting from points of stress concentration in the scallop. The hardening associated with punching may prevent the formation of such cracks in punched stiffeners.

6. Unjointed channel stiffeners riveted to the plating withstood a larger number of cycles than stiffeners welded on with continuous fillet welds.

7. Welded joints in stiffeners generally have the effect of lowering the fatigue strength in comparison with that of unjointed stiffeners. The decrease, however, is not as much for good butt welds as that caused by drilled holes in unjointed stiffeners.

8. The fatigue strength of butt welds in stiffeners depends to some degree on the type of electrode used. Butt welds made with hydrogen controlled electrodes give better values than those made with ordinary electrodes.

9. The removal of the reinforcement of butt welds by grinding does not improve the fatigue strength of butt welds in rolled sections. It is conceivable, however, that if the reinforcement were removed by filing or other methods of machining, an improvement might be obtained.

10. The fatigue strength of butt welds in stiffeners does not appear to be greatly influenced by internal flaws. The results obtained from some of the butt welds made in shipyards, intentionally incorporating flaws, were as good as those obtained from some butt welds made in the laboratory with the greatest care.

11. Of several different types of reinforcing straps for butt welds, the diamond-shaped strap has proved superior to any other type of strap, provided that the fillet welds connecting the strap to the flange are very carefully sculptured with a rotary file to eliminate all traces of undercut and to impart to these fillet welds a smooth concave contour. With such straps some improvement in fatigue life has been obtained, even in comparison with the best butt welds tested.

12. No other type of strap of those tested can be considered an effective reinforcement even for butt welds of low quality, with the exception of the Gardiner strap. This strap is an effective reinforcement for poor quality butt welds. It is recommended that this strap should be made from a 30-degree isosceles triangle rather than from a 45-degree isosceles triangle, the former giving a somewhat better performance than the latter.

A Survey of Arc Welding in Gaseous Atmosphere*

An interesting historical review of successful and unsuccessful attempts to provide arc shielding of the molten weld metal from atmospheric contamination

THE electric arc yields a large amount of heat, which produces a localized fusion of metals and thus is a suitable agent for joining operations. But the necessity of melting the elements involved in welding, causes some chemical and structural changes in the pool more or less apparent as the purity of the metals decreases or whenever they are altered by the contact of air at high temperature.

The energy of the electric arc is therefore not easily applied to welding, unless it is shielded from the surrounding air or used in conjunction with an improving metallurgical agent of some kind.

Up to now this was almost exclusively achieved by electrode coatings which facilitate the ionization of the air, surrounding the metal drops as soon as they leave the electrodes, and purifying and protecting the weld pool by their close contact with it.

By maintaining a selected atmosphere around the pool and the filler metal similar results are obtained restoring the electric arc process to its initial simplicity. The foregoing application is made easier as the metallurgical factor derived habitually from the coating will have a secondary importance, whether pure metals are involved in the welding or as more generally, stabilized alloys covered only with thin films of oxides or pickling residues.

* Translation from French made by L'Air Liquide Society, Montreal, Canada, of an article published in *Soudure et Techniques Connexes*, vol. V, 1951, pp. 179–181.

Today, technically speaking, the benefit derived from this solution affects mostly argon and helium. This has not always been true since these two gases were not readily available. Therefore, it is not at all surprising, that the first attempts to use gases as protective atmospheres led to the use of the more common ones. Although a serious effort to put these gases to work in the welding field did not yield notable results, we consider them worth describing due to the useful data provided in their application.

SOME EARLY ATTEMPTS

Nitrogen[1] was the first gas susceptible to such an application. For a long period it was erroneously presumed to be an inert gas. In the course of trial its injection was realized by means of hollow electrodes or with a shield surrounding the electrodes. This last disposition was retained in all welding applications involving purely inert atmosphere. The welds obtained by this method have shown the same brittleness as the oxidized welds performed in atmospheric air. Also the bad results were due to nitrides resulting from the metal-nitrogen combination.

Other unsuccessful tests were then conducted with carbonic gas and water vapor which were then considered as inert elements; later city lighting gas was tried.[2] At high temperature the first two gases are powerful oxidizing agents, in spite of their partial dissociation, whereas the lighting gas has a carburizing effect.

Following the application of inert atmospheres, researchers have indeed perceived the particular implications of their use in arc welding with bare electrodes. However, after several unsuccessful trials, it was rather inevitable that they should abandon these initial endeavors and engage themselves in fields already explored. Some gaseous atmospheres were already considered as very efficient; for instance, oxyacetylene welding—the technique of which was already well established—also atomic hydrogen welding a newcomer.

The oxyacetylene flame, which has been applied since 1901, creates a gaseous area consisting essentially of hydrogen (under two forms: diatomic and monatomic) and carbon monoxide.[3] Its properties are very convenient and it provides the most appropriate method for ordinary welding of small thicknesses. Its timely introduction had removed the drawbacks of the oxyhydrogen flame, producing mainly water vapor, and showing oxidizing power at high temperature.

Atomic hydrogen, discovered by Langmuir in 1911, had given way to many outstanding applications.[4] Yet this process was being developed at a slow rate due to the lack of versatility, because it required special costly equipment and skilled personnel.

It was believed that the Alexander Process[5] could retain the protective qualities reputedly held by hydrogen, while the energy of the arc was directly put to work. It was employed effectively during a number of years for automatic welding at the General Electric plants in the United States. The arc was ignited in the hydrogen streaming out of the torch tip surrounded with flames. The no-load voltage was over 120 v., a value too high for ordinary welding machines. The welds were not free of defects, such as blowholes or lack of penetration. Finally, on account of uneven results the process was discarded around 1932.

HYDROGEN AND CARBON MONOXIDE

An improvement was sought, and it was noted that in an atmosphere of 30% hydrogen and 70% carbon monoxide the arc was sustained with electrical characteristics very similar to those obtained in atmospheric air.[6] The no-load voltage was falling to 70 v. and the working voltage to 25 v.

The carbon monoxide being highly toxic, it was not practical to store it. Only recently has it been possible to obtain it in cylinders. To overcome this drawback, methyl alcohol (methanol CH_3OH) was vaporized at a temperature of 100° C., its dissociation into hydrogen and carbon monoxide starting at 700° C. in proportions close to those mentioned above. One portion of the gas burns in the arc in contact with the air, and the welding operation was executed in a flame 6 to 8 in. long.[7] The welds were fairly solid, but the necessity of maintaining a vapor stream was another drawback of the operation which prevented a more extensive application of the process.

An attempt was also made to obtain the carbon monoxide-hydrogen mixture through the reaction of propane on carbonic gas at the high temperature of the arc.[8]

During all these tests the main effect of the introduction of carbon monoxide consisted in reducing the striking voltage of the arc blowing in pure hydrogen. It was soon found that the addition of a small percentage of argon would bring the same result, but this gas was not at the time commercially available.[9]

As these tests gave no definite result, the association of the electric current and the oxyacetylene flame was soon proposed and applied. It is the Arcogen process launched in 1930.[10] The intensity of the current used was as low as 50 A. The welds were sound, but the technique employed had some drawbacks, resulting from both processes and not compensated by a notable improvement, as it was actually verified.

ELECTRODE COATINGS

In the meantime the progress obtained in the fabrication of coatings diverted attention for some time from the direct use of gases.

It is significant to note that those promoting the electrode coatings technique had a firm belief in the substitution of hydrogen which in some way reacts chemically like a metal, by vapors of various metals, such as calcium, sodium, manganese, more easily

ionized and having the same strong attraction for oxygen.[11] In fact we know that the action of coatings has a much larger scope.

However, the cellulose volatile coatings formulated at an early date by A. O. Smith,[12] were exclusively the producers of carbon monoxide, hydrogen and small amounts of slag. One can consider that the process is a direct result of the technique of gaseous atmospheres.

One automatic machine was designed by Lincoln, following the same principle.[13] The gaseous mixture was created by combustion of a paper cord before the electrode. The paper cord, according to the inventor, could be impregnated with water.

Manufacture of coated electrode retained, however, its wide empirical character. Also the expansion of arc welding during and after the First World War emphasized the gap between the importance of the forthcoming uses and the lack of theoretical knowledge relating to the electric arc. A basic research was started in various laboratories, among which were Lehigh University and the Battelle Memorial Institute. Outstanding experimental work was accomplished which served to enlighten the extraordinary complexity of the phenomena taking place in the electric arc.

STUDIES OF THE ARC

In the first place the experiments of Suits have provided an acceptable appraisal of the temperature of the arc.[14] This value is important in itself; it is directly related to the ionization potential of the gases in the arc which—as a result—it is possible to identify.[15] It was learned also that the ions determining the transportation of the current inside the arc were arising, except in the case of refractory electrodes, from metallic vapors originating in the electrode and the work. However, the metal stays far from its boiling point and the vapors have a low pressure.[16] They are, therefore, more or less penetrated by the gases of the surrounding atmosphere, which have possibilities of acting chemically on the molten pool.

It is known that the incorporation of certain elements in the electrodes, even in a small quantity, has a powerful effect on the behavior of the arc.

These conditions were noted long ago by Wehnelt in the case of basic oxides, for their emissive power. When incorporated in the electrodes or through a simple application to the surface they enable an intense current to go through the electrode remaining at a relatively low temperature, and they have, moreover, a stabilizing effect on the arc. This influence of oxygen is mainly materialized in the so-called cold cathodes, that is, in usual metals. This was definitely brought to light by the works of Suits and Ockers.[17]

It is also the property, not yet well known, of various elements modifying the surface of the melting end of electrodes and accelerating the melting process, decreasing the size of the formed droplets, thus facilitating the penetration.[18]

A third series of studies deals with the craters or depressions formed on the surface of the liquid pool of the weld, but only in certain circumstances.[19] It has been observed that these craters do not occur when operating, at the usual rates of welding currents, in the following atmospheres of pure gases: hydrogen, helium, argon, nitrogen. On the contrary they appear when the inert gases are mixed with a small quantity of oxygen.

This feature has some interest, for it is easily seen that the existence of a depression in the center of the pool will promote the transmission of the heat to the the metal of the workpiece, in other words it will contribute directly to the penetration. Strictly speaking, however, the latter depends only on the quantity of heat becoming available in the metal in a given time, that is, on the heat delivered at the level of the pool and on the welding speed.

The beads deposited in an atmosphere of pure nitrogen, although deprived of a crater, definitely show a satisfactory penetration.[20] This fact suggests that the diatomic gases such as nitrogen can provide spontaneously the heat required, when there is no crater, by their dissociation in the arc and recombination in the same way as atomic hydrogen, upon contact with the pool. The monatomic inert gases, being unable to release chemical energy, the penetration with the consumable electrode should be obtained only by increasing the power of the arc—that is, by using high current density, therefore a high welding current.

At present great hopes are founded on the direct examination of the arc obtained by cinematography at high speed.

Let us consider for instance a welding operation on a piece of steel, in argon atmosphere, with a tungsten electrode, d.-c. (electrode negative) and no filler metal. The brilliant metallic vapors produced on the workpiece are perfectly apparent and they seem to occupy the whole column of the arc. Apparently, the argon would help only to shield the arc from the surrounding air. Actually, due to the very low pressure of the metallic vapors, relatively large proportions of argon are certainly diffused in the column and mix with the vapors arising over the pool.

By operating in argon atmosphere with d.-c. but using consumable electrodes, engineers of Linde Air Products by means of a film, giving 14,500 images per second, have also recognized the existence of metallic vapors.[21] But the vapors appear only upon contact with the melted metal and seem to be cut from the electrode with each parting of a drop. The outstanding fact, as yet unexplained, featured by the film, is the presence of these vapors inside a luminous shield, although less brilliant, which stays permanently and seems to insure the continuous transfer of current.

These experiments have given a definite insight into the structure of arcs in purely inert atmosphere, but without elucidating fully the mechanism of the process. The constantly growing accuracy of running experiments will likely lead eventually to real improvements

in a field being explored by so many research workers. It is expected that the technique regarding the use of gaseous atmospheres will not be without further development and that the particular properties of polyatomic gases will be used for the benefit of the welding arc.

As already seen, nitrogen like hydrogen is capable of being dissociated and may be a source of complementary chemical energy, capable of increasing the efficiency of the results. The carbon monoxide associated to a reasonable rate of carbonic gas may produce interesting results.

The experiments of Doan at Lehigh University have shown that by adding oxygen to the gaseous atmosphere smaller drops come from the end of electrodes and the formation of a crater on the piece is obtained, thereby improving the penetration.[22]

On the other hand the ability of the molecules of some gases, such as oxygen, to take the electrons for forming negative ions, is well known. Although a point of discussion, this action could have an influence on the shape of welding arcs.

Lastly, the studies of Alexander on hydrogen atmospheres have been resumed[23] and have permitted the verification of the already known characteristics of the arc, that is, on one hand the necessity of a high no-load voltage to insure the stability of the arc and, on the other hand, the presence of blowholes in the deposited metal. If the electrode wire is not made of steel, but of pure iron, the melted drop absorbs so much hydrogen that this gas when evolved distorts the surface of the welding bead. Moreover by gaseous cathodic loading of martensitic steels, the influence of hydrogen on the cracking of these steels was given proof.[24]

The gases emitted by the various types of coated electrodes have been submitted to analyses and have revealed that they are the constituents at equilibrium of water gas, with carbon monoxide, some hydrogen and a relatively small quantity of carbonic gas and water vapor.[25] As to the fundamental reactions resulting from the gaseous protection, all the coated electrodes either cellulosic, acid or purely mineral behave qualitatively in a similar way. The lime-ferritic electrodes are a particular case because their coating is often studied with a view to reducing the hydrogen emission to a minimum rate when they are used for the welding of crack sensitive steels.[26]

Due to a scientific research pursued continuously during twenty years, important data has been collected on the pecularities of arc atmospheres, allowing their classifications with regard to their protective action and their ability to improve the striking and sustaining of the arc. It is certain that the use of pure argon has had a peremptory influence on the progress of welding with bare rods in shielded atmospheres, but obviously this technique is subject to improvement and the efficiency will be increased by a better knowledge of the behavior of the electric arc and a better insight into the numerous factors involved in the operation.

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Behavior of an Idealized Steel H Column Above the Elastic Range

A mathematical method of analyzing H columns bent about the strong axis. Presented also are the type of failure and the magnitude of the direct load and bending moments causing it

by Walter H. Weiskopf

INTRODUCTION

WITH the present trend of utilizing structural materials to a greater and greater extent, it becomes important to gain more knowledge of the conditions under which columns fail and the method of failure. In particular this applies to columns subject to end bending moments. Failure, of course, takes place when some fibers are stressed to their ultimate and therefore a proper analysis should take into account the portions of the column where the stresses go beyond the elastic range.

Presented here is a mathematical method of analyzing an idealized steel H column. The column is idealized in two respects:

1. It is assumed that the stress-strain diagram for steel consists of a series of three straight lines.

2. It is assumed that the column consists of two flanges only. The web is assumed to have no magnitude but joins the flanges so that they act together.

Column failure is caused by one of two conditions: (1) instability or buckling of the main member, a rapidly increasing deflection causing a corresponding increasing bending moment; or (2) local buckling or rippling of the more heavily loaded flange. In actual failure one of these causes immediately involves the other, collapse occurs and it is usually impossible to determine which came first. From a mathematical approach, however, they are distinct and the criterion for failure may depend on either one. The analysis here presented indicates the type of failure and the magnitude of the direct load and bending moments causing it. The analysis is confined to action in the plane of the column web. That is, it does not consider buckling about the weak axis of the H section or twisting of the column shaft.

While the analysis deals directly with an idealized H section bent about its strong axis, the results arrived at throw light on the behavior of other column shapes and in some respects apply directly to other shapes.

The method can be applied to members subject to direct compression and any kind of bending loads but only a limited number of cases are presented. These are:

(*a*) Pin-ended column.
(*b*) Column with equal end moments (single curvature).
(*c*) Column with unequal end moments.
(*d*) Column with end moment at one end and pin at the other.
(*e*) Column with equal end moments (double curvature).
(*f*) Column with end moment at one end, fixed at the other.

THE STRESS-STRAIN RELATION

Figure 1* shows typical stress-strain diagrams for structural steel. In the elastic range the stress-strain ratio is the modulus of elasticity, E. In the plastic range the diagram is a horizontal straight line a distance σ_y above the origin. This is the assumption generally made in the plastic range. In the strain-hardening range it is here assumed that the diagram is a straight line whose equation is

$$\sigma = C\epsilon + B \qquad (1)$$

It is seen that B is the intercept on the vertical axis and in dimensional units is in pounds per square inch. C is the slope of the line and is analogous to E.

Equation 1 can also be written,

$$\epsilon = \frac{\sigma - B}{C} \qquad (2)$$

Figure 1 shows specimens tested in tension. The curve for compression for very short blocks, which cannot buckle, is similar. However, a beam or column flange would fail by local buckling at a load far below the ultimate in tension. The value at which local

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* Figure 1 is taken from "Residual Stress and Yield Strength of Steel Beams" by Ching Huan Yang, Lynn S. Beedle and Bruce G. Johnston, Figure 5B, page 228-s of the Supplement to THE WELDING JOURNAL, April 1952.

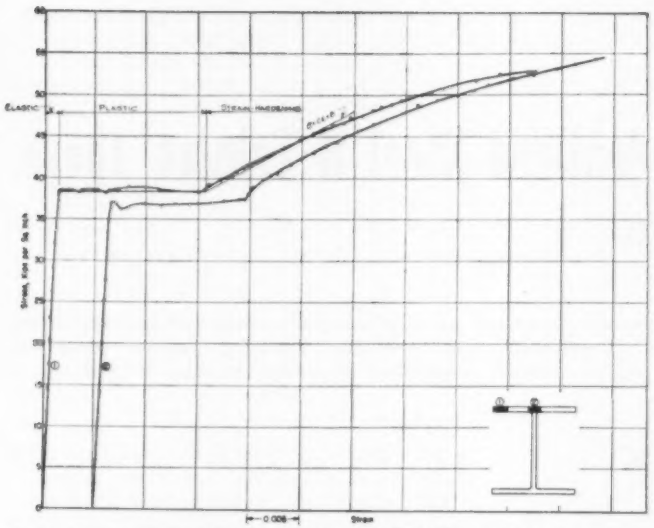

Fig. 1 Tension stress-strain curves for an 8WF40 beam (including strain-hardening range)

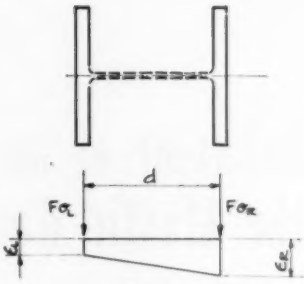

Figure 2

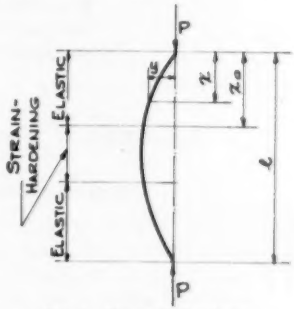

Fig. 3 Pin-ended column

buckling would occur depends, among other factors, on the ratio of flange width to thickness, the depth of the section and amount of support given by the web, the length of the member, the degree of lateral support, etc. It is obviously impossible to state a unit stress at which buckling will start but experiments indicate that perhaps 5 kips per square inch above the yield point is as much as a flange could be expected to carry.

FLEXURE ABOVE THE ELASTIC RANGE

In the elastic range the relation of external bending moment to change in slope is well known. The corresponding relation above the elastic range is derived as follows: Fig. 2 represents the cross section of a steel H column. The web is neglected and the area of each flange is F. σ_L and σ_R are the unit stresses on the left and right flanges and it is assumed that σ_L is less than σ_R and is in the elastic range. σ_R is above the elastic range. The direct load on the column is P and the bending moment at the section shown is M. Then

$$\sigma_L = \frac{P}{2F} - \frac{M}{Fd} \tag{3}$$

$$\sigma_L = \frac{P}{2F} + \frac{M}{Fd} \tag{4}$$

For this idealized column Fd is the section modulus and the moment of inertia is $Fd^2/2$.

Since the left side is in the elastic range the unit strain is

$$\epsilon_L = \frac{\sigma_L}{E} \tag{5}$$

The right side is in the strain-hardening range, and therefore, from Equation 2

$$\epsilon_R = \frac{\sigma_R - B}{C} \tag{6}$$

The change in slope per unit length of column is

$$\frac{d^2y}{dx^2} = \frac{\epsilon_R - \epsilon_L}{d} \tag{7}$$

Substituting 5 and 6 in 7

$$\frac{d^2y}{dx^2} = \frac{\sigma_R - B}{Cd} - \frac{\sigma_L}{Ed} \tag{8}$$

Using Equations 3 and 4

$$\frac{d^2y}{dx^2} = \frac{M}{Fd^2}\left(\frac{1}{C} + \frac{1}{E}\right) + \frac{P}{2Fd}\left(\frac{1}{C} - \frac{1}{E}\right) - \frac{B}{Cd} \tag{9}$$

Equations 9 in the strain-hardening range corresponds to the familiar expression

$$\frac{d^2y}{dx^2} = \frac{M}{EI}$$

of the elastic range and can be used to solve flexure problems in a similar manner. This will be illustrated for several cases.

PIN-ENDED COLUMN

Let Fig. 3 represent such a column and assume that P is known and is so great that one flange at the central portion of the column goes beyond the elastic range. Let the bending moment at the limit of the elastic range be represented by M_0. Obviously at this point

the maximum unit stress, $\sigma_R = \sigma_y$. Then from Equation 4

$$M_0 = \sigma_y Fd - \frac{Pd}{2} \tag{10}$$

Let the coordinate at this point be x_0.

In the elastic range (x is less than x_0)

$$\frac{d^2y}{dx^2} = \frac{M}{EI} = -\frac{Py}{EI} \tag{11}$$

The solution of this is

$$y = c_1 \sin\frac{x}{j} + c_2 \cos\frac{x}{j} \tag{12}$$

and its derivatives are

$$\frac{dy}{dx} = \frac{c_1}{j}\cos\frac{x}{j} - \frac{c_2}{j}\sin\frac{x}{j} \tag{13}$$

$$\frac{d^2y}{dx^2} = -\frac{c_1}{j^2}\sin\frac{x}{j} - \frac{c_2}{j^2}\cos\frac{x}{j} = -\frac{y}{j^2} \tag{14}$$

$$M = -Pc_1 \sin\frac{x}{j} - Pc_2 \cos\frac{x}{j} \tag{15}$$

In these equations

$$j = \sqrt{\frac{EI}{P}} \tag{16}$$

In the strain-hardening range again $M = -Py$ and from equation 9

$$\frac{d^2y}{dx^2} = -\frac{Py}{Fd^2}\left(\frac{1}{C} + \frac{1}{E}\right) + \frac{P}{2Fd}\left(\frac{1}{C} - \frac{1}{E}\right) - \frac{B}{Cd} \tag{17}$$

The solution of this is

$$y = c_3 \sin\frac{x}{k} + c_4 \cos\frac{x}{k} + m \tag{18}$$

and its derivatives are

$$\frac{dy}{dx} = \frac{c_3}{k}\cos\frac{x}{k} - \frac{c_4}{k}\sin\frac{x}{k} \tag{19}$$

$$\frac{d^2y}{dx^2} = -\frac{c_3}{k^2}\sin\frac{x}{k} - \frac{c_4}{k^2}\cos\frac{x}{k} \tag{20}$$

$$M = -Pc_3 \sin\frac{x}{k} - Pc_4 \cos\frac{x}{k} - Pm \tag{21}$$

In these expressions

$$k = \sqrt{\frac{Fd^2CE}{P(C + E)}} \tag{22}$$

$$m = \frac{d(E - C)}{2(E + C)} - \frac{BEFd}{P(E + C)} \tag{23}$$

The constants k and m depend on the column properties and on the load. k is analogous to j in the elastic range.

Two of the constants of integration are evaluated as follows: When $x = 0$, $y = 0$ and therefore $c_2 = 0$. From symmetry when $x = l/2$, $dy/dx = 0$. Therefore

$$c_3 = c_4 \frac{\sin\dfrac{l}{2k}}{\cos\dfrac{l}{2k}} \tag{24}$$

Substituting in Equations 12 to 15, in the elastic range

$$y = c_1 \sin\frac{x}{j} \tag{25}$$

$$\frac{dy}{dx} = \frac{c_1}{j}\cos\frac{x}{j} \tag{26}$$

$$\frac{d^2y}{dx^2} = -\frac{c_1}{j^2}\sin\frac{x}{j} \tag{27}$$

$$M = -Pc_1 \sin\frac{x}{j} \tag{28}$$

In the strain-hardening range Equations 18 to 21 become

$$y = c_4 \cos\frac{1}{k}\left(\frac{l}{2} - x\right) + m \tag{29}$$

$$\frac{dy}{dx} = \frac{c_4}{k}\sin\frac{1}{k}\left(\frac{l}{2} - x\right) \tag{30}$$

$$\frac{d^2y}{dx^2} = -\frac{c_4}{k^2}\cos\frac{1}{k}\left(\frac{l}{2} - x\right) \tag{31}$$

$$M = -Pc_4 \cos\frac{1}{k}\left(\frac{l}{2} - x\right) - Pm \tag{32}$$

There are still two unknown constants c_1 and c_4 and in addition the coordinate x_0 is not known. However, when $x = x_0$ the slopes and bending moments in the adjacent sections are equal. This gives two conditions and the third is that the bending moment at this point equals M_0. Thus

$$\frac{c_1}{j}\cos\frac{x_0}{j} = \frac{c_4}{k}\sin\frac{1}{k}\left(\frac{l}{2} - x_0\right) \tag{33}$$

$$-Pc_1 \sin\frac{x_0}{j} = -Pc_4 \cos\frac{1}{k}\left(\frac{l}{2} - x_0\right) - Pm = M_0 \tag{34}$$

Solving Equations 33 and 34

$$\tan\frac{x_0}{j}\tan\frac{1}{k}\left(\frac{l}{2} - x_0\right) - \frac{k}{j} \times \frac{M_0}{M_0 + Pm} = 0 \tag{35}$$

$$c_1 = -\frac{M_0}{P \sin\dfrac{x_0}{j}} \tag{36}$$

$$c_4 = -\frac{M_0 + Pm}{P \cos\dfrac{1}{k}\left(\dfrac{l}{2} - x_0\right)} \tag{37}$$

In Equation 35 x_0 is the only unknown, the other quantities being the load P, and properties of the column. x_0 can be found by trial. When x_0 is known the constants c_1 and c_4 are given by Equations 36 and 37 and then Equations 25 to 32 give a complete solution to the problem.

The expression k/j which appears in Equation 35 is found from Equations 16 and 22 to be

$$\frac{k}{j} = \sqrt{\frac{2C}{C + E}} \tag{38}$$

It thus depends on the characteristics of the material only and is independent of the column shape or dimensions.

NUMERICAL EXAMPLE OF PIN-ENDED COLUMN

Plotting these curves for a specific case is enlightening. The following values will be used:

For the material

$E = 30{,}400$ kips/sq. in.
$\sigma_y = 40$ kips/sq. in.
$C = 667$ kips/sq. in.
$B = 28$ kips/sq. in.

$$\frac{j}{k} = \sqrt{\frac{2C}{C + E}} = 0.207.$$

For the column

$I = 109.5$ in.^{4}
$F = 4.13$ sq. in.
$d = 7.28$ in.
$l = 203$ in.

For such a column the Euler load is

$$P_e = \frac{\pi^2 EI}{l^2} = 800 \text{ kips}$$

The load for an average yield point stress is

$$P_y = 2F\sigma_y = 330 \text{ kips}$$

It was found that for every value of P less than P_y a real solution existed with a definite value of x_0 and a definite shape for the neutral surface. Values of the center deflection, y_4, are plotted in Fig. 4. Each point of this graph represents a curved position for the column at which the internal stresses are in equilibrium with the load P. If the column for some reason were deflected a greater amount, it would be unstable and immediately buckle. If it were deflected a smaller amount it would (from purely mathematical considerations) return to a straight line. The magnitude of the center deflection for equilibrium decreases as the load increases and becomes zero when the load reaches the yield point load, P_y. For the yield point load, then, the column is in equilibrium in its originally straight position only and any deflection will cause instability.

The maximum unit stress at the center for various values of P is also plotted in Fig. 4. It is seen to go only slightly above the yield point.

It is interesting to see what the mathematics indicates for loads greater than P_y. For this case the entire column is in the strain-hardening range and $x_0 = 0$. Equations 29 to 32 can then be used, and the constant c_4 can easily be evaluated from the condition that when $x = 0$, $y = 0$. Computations show that for a load only slightly over the yield point load, P_y, the unit stress at the center is fantastically high. Thus if $P = 350$ kips (only 6% above the yield point load) the indicated stress at the center is 183 kips per square inch.

The inescapable conclusion appears to be that the maximum load for a pin-ended column is that which causes an average unit stress equal to the yield point.

COLUMN SUBJECTED TO EQUAL END MOMENTS (SINGLE CURVATURE)

This case is shown in Fig. 5. The bending moment at any point is

$$M = -Py + M_A \qquad (39)$$

Proceeding with this expression for the bending moment in a manner similar to the previous case, the solution is as follows:

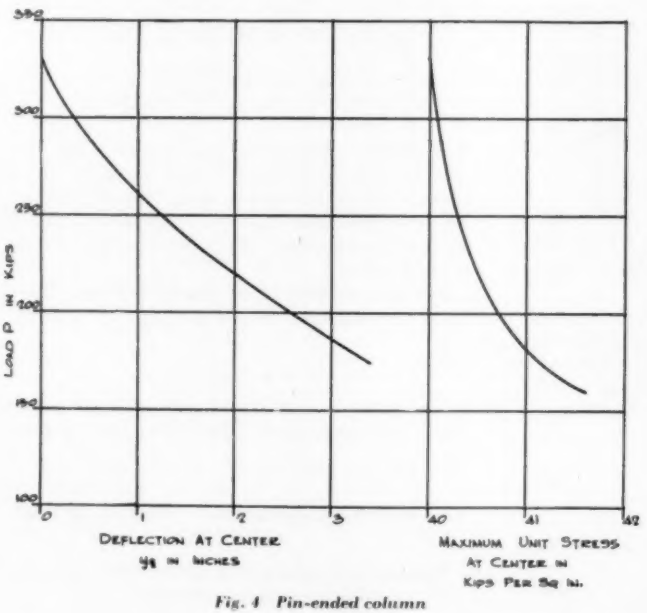

Fig. 4 Pin-ended column

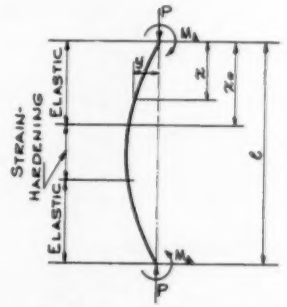

Fig. 5 Equal-end moments

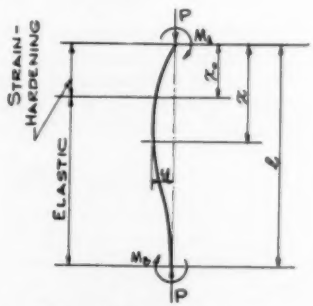

Fig. 6 Unequal end moments

In the elastic range

$$y = c_1 \sin \frac{x}{j} - \frac{M_A}{P} \cos \frac{x}{j} + \frac{M_A}{P} \tag{40}$$

$$\frac{dx}{dx} = \frac{c_1}{j} \cos \frac{x}{j} + \frac{M_A}{Pj} \sin \frac{x}{j} \tag{41}$$

$$\frac{d^2y}{dx^2} = -\frac{c_1}{j^2} \sin \frac{x}{j} + \frac{M_A}{Pj^2} \cos \frac{x}{j} \tag{42}$$

$$M = -Pc_1 \sin \frac{x}{j} + M_A \cos \frac{x}{j} \tag{43}$$

In the strain-hardening range

$$y = c_2 \cos \frac{1}{k}\left(\frac{l}{2} - x\right) + \frac{M_A + Pm}{P} \tag{44}$$

$$\frac{dy}{dx} = \frac{c_2}{k} \sin \frac{1}{k}\left(\frac{l}{2} - x\right) \tag{45}$$

$$\frac{d^2y}{dx^2} = -\frac{c_2}{k^2} \cos \frac{1}{k}\left(\frac{l}{2} - x\right) \tag{46}$$

$$M = -Pc_2 \cos \frac{1}{k}\left(\frac{l}{2} - x\right) - Pm \tag{47}$$

The value of x_0 can be obtained from the equation

$$\frac{j}{k}(M_0 + Pm) \tan \frac{x_0}{j} \tan \frac{1}{k}\left(\frac{l}{2} - x_0\right) - M_0 + \frac{M_A}{\cos \frac{x_0}{j}} = 0 \tag{48}$$

Then

$$c_1 = \frac{-M_0 + M_A \cos \frac{x_0}{j}}{P \sin \frac{x_0}{j}} \tag{49}$$

$$c_2 = -\frac{M_0 + Pm}{P \cos \frac{1}{k}\left(\frac{l}{2} - x_0\right)} \tag{50}$$

As in the previous case x_0 can be determined by trial from Equation 48. Then c_1 and c_2 can be determined from 49 and 50 and then 40 to 47 give the complete solution.

When $x_0 = l/2$ the column is all elastic. For this case

$$c_1 = \frac{M_A}{P} \times \frac{\cos \frac{l}{j} - 1}{\sin \frac{l}{j}} \tag{51}$$

and equations 40 to 43 apply. The maximum moment which is at the center of the column is

$$M_{\frac{l}{2}} = \frac{M_A}{\cos \frac{l}{2j}} \tag{52}$$

From Equation 52 values of M_A and P can be plotted which will cause a unit stress at the center of the column equal to the yield point. Such a plotting of M_A and P (sometimes called an "interaction curve") is the limit of the elastic range.

It was impossible to find values of x_0 to satisfy Equation 48 for values of M_A and P above the elastic range. The fact that there is no solution can be verified mathematically. The critical value at which M_A becomes greater than the M_A for the limit of the elastic range is found by equating dM_A/dx_0 to zero when $x_0 = l/2$. Thus

$$\frac{dM_A}{dx_0} = -\frac{1}{k}(M_0 + Pm)\left[\cos \frac{x_0}{j} \tan \frac{1}{k}\left(\frac{l}{2} - x_0\right) - \frac{j}{k} \sin \frac{x_0}{j} \sec^2 \frac{1}{k}\left(\frac{l}{2} - x_0\right)\right] - \frac{M_0}{j} \sin \frac{x_0}{j} \tag{53}$$

Placing $x_0 = l/2$ and equating to zero leads to the expression

$$\frac{C}{E} = 1 - \frac{B}{\sigma_y} \tag{54}$$

But this equation is entirely inconsistent with the properties of steel and therefore no solution for a steel column exists.

From the nonmathematical approach it is easy to see why this case becomes unstable when the yield point is passed. When the fibers near the center of the column enter the plastic or strain-hardening range, a great increase in the deflection, y, occurs which causes a correspondingly larger bending moment, which in turn further increases the deflection. In short this is collapse. This likewise applies to columns of any cross section.

The conclusion can then be drawn that this case is unstable if the values of M_A and P cause the maximum unit stress to go beyond the elastic range.

COLUMN SUBJECTED TO UNEQUAL END MOMENTS

In this case (shown on Fig. 6) the top moment is taken so large that the upper portion of the column goes beyond the elastic range, but the remainder of the column is elastic. That is

$$M_A > M_0 > M_B \tag{55}$$

The bending moment at any point is

$$M = -Py + M_A - (M_A - M_B)\frac{x}{l} \tag{56}$$

Using this equation and following the same procedure as in the pin-ended column, expressions for the two sections of the column can be obtained. The constants of integration can be eliminated by the end conditions and by equating the slopes and moments where the sections join. Again at this point the moment equals M_0. The resulting solution is, in the strain-hardening range

$$y = c_1 \sin \frac{x}{k} + \frac{M_A + Pm}{P}\left(1 - \cos \frac{x}{k}\right) - \frac{M_A - M_B}{Pl}x \tag{57}$$

$$\frac{dy}{dx} = \frac{c_1}{k} \cos \frac{x}{k} + \frac{M_A + Pm}{Pk} \sin \frac{x}{k} - \frac{M_A - M_B}{Pl} \tag{58}$$

$$\frac{d^2y}{dx^2} = -\frac{c_1}{k^2} \sin \frac{x}{k} + \frac{M_A + Pm}{Pk^2} \cos \frac{x}{k} \tag{59}$$

$$M = -Pc_1 \sin \frac{x}{k} + (M_A + Pm) \cos \frac{x}{k} - Pm \tag{60}$$

and in the elastic range

$$y = -c_1 \sin \frac{l-x}{j} - \frac{M_B \cos \frac{x}{j}}{P \cos \frac{l}{j}} + \frac{M_A}{P}\left(1 - \frac{x}{l}\right) + \frac{M_B x}{Pl} \quad (61)$$

$$\frac{dy}{dx} = \frac{c_2}{j} \cos \frac{l-x}{j} + \frac{M_B \sin \frac{x}{j}}{Pj \cos \frac{l}{j}} - \frac{M_A - M_B}{Pl} \quad (62)$$

$$\frac{d^2y}{dx^2} = \frac{c_2}{j^2} \sin \frac{l-x}{j} + \frac{M_B \cos \frac{x}{j}}{Pj^2 \cos \frac{l}{j}} \quad (63)$$

$$M = Pc_2 \sin \frac{l-x}{j} + M_B \frac{\cos \frac{x}{j}}{\cos \frac{l}{j}} \quad (64)$$

The value of x_0 can be obtained from the expression

$$M_0 \cos \frac{l}{j}\left(\cos \frac{x_0}{k} \sin \frac{l-x_0}{j} + \frac{k}{j} \sin \frac{x_0}{k} \cos \frac{l-x_0}{j}\right) - M_B \frac{k}{j} \sin \frac{x_0}{k} \cos \frac{l}{j} - \left(M_A + Pm - Pm \cos \frac{x_0}{k}\right) \cos \frac{l}{j} \sin \frac{l-x_0}{j} = 0 \quad (65)$$

And then values of c_1 and c_2 are

$$c_1 = \frac{k}{Pj} \times \frac{-M_B + (M_A + Pm)\left(\cos \frac{x_0}{k} \cos \frac{l-x_0}{j} - \frac{j}{k} \sin \frac{x_0}{k} \sin \frac{l-x_0}{j}\right) - Pm \cos \frac{l-x_0}{j}}{\cos \frac{x_0}{k} \sin \frac{l-x_0}{j} + \frac{k}{j} \sin \frac{x_0}{k} \cos \frac{l-x_0}{j}} \quad (66)$$

$$c_2 = \frac{-M_B\left(\cos \frac{x_0}{k} \cos \frac{x_0}{j} + \frac{k}{j} \sin \frac{x_0}{k} \sin \frac{x_0}{j}\right) + \left(M_A + Pm - Pm \cos \frac{x_0}{k}\right) \cos \frac{l}{j}}{P\left(\cos \frac{x_0}{k} \sin \frac{l-x_0}{j} + \frac{k}{j} \sin \frac{x_0}{k} \cos \frac{l-x_0}{j}\right) \cos \frac{l}{j}} \quad (67)$$

This case is general for any values of M_A and M_B, provided that the column has an end section in the strain-hardening range and the remainder in the elastic range. Some special cases are simpler to study.

COLUMN SUBJECTED TO END MOMENT AT THE TOP PIN-CONNECTED AT THE BOTTOM

This case can be obtained from the preceding by making M_B equal to zero. Equations 57 to 64 apply but the expression for x_0, equation 65, can be simplified. It becomes

$$M_A - M_0 \cos \frac{x_0}{k}\left(1 + \frac{k \tan \frac{x_0}{k}}{j \tan \frac{l-x_0}{j}}\right) + Pm\left(1 - \cos \frac{x_0}{k}\right) = 0 \quad (68)$$

c_1 and c_2 can be found from 66 and 67 by making $M_B = 0$.

To see better what the equations mean, values were computed for a column with the same length and cross section as the previous example, but for various values of P and M_A.

For on all-elastic column, since the maximum moment is at the end, the interaction curve for a maximum stress equal to the yield point stress is a straight line as shown on Fig. 7. Above the elastic range, solutions can be found by this analysis for values of P and M_A. The upper limit of these is also plotted on Fig. 7. Above this limit the column becomes unstable.

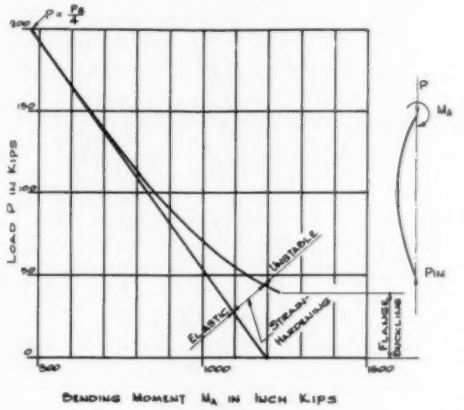

Fig. 7

One quarter of the Euler load for an all-elastic column is the critical load above which the maximum moment shifts to the central portion. For a load between one-fourth and one-eighth of the Euler load, the strain-hardening range is extremely small and, as Fig. 7 shows, it is only for relatively small values of P that it has a magnitude worth considering. For these small values, M_A can become considerably larger than M_0. It is possible here, however, that the column flange may buckle locally before the column as a whole becomes unstable. In the strain-hardening range the maximum moment is not necessarily at the very end of the column. Figure 8 is a plotting of the bending moment along the length of column for a load of $P = 40$ kips and an end moment of 1232 in. kips. The maximum moment, 1288 in. kips, is 25.8 in. from the top. The indicated unit stress at this point is 47.7 kips per square inch. The column flange would undoubtedly have buckled locally before this stress could be reached.

For values of P less than 40 kips the analysis indicates that the column as a whole is stable for large values of M_A. Failure in this area would therefore occur by local buckling of the flange. This analysis

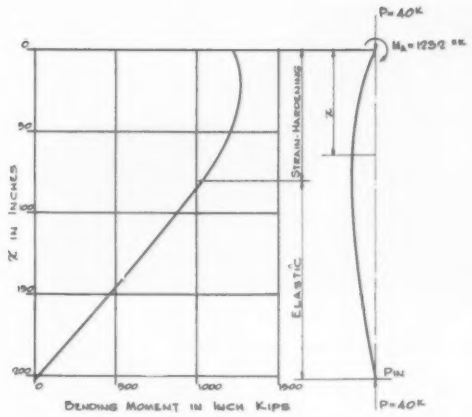

Fig. 8

can be used to determine where such buckling is likely to occur.

COLUMN SUBJECTED TO EQUAL END MOMENTS (DOUBLE CURVATURE)

Since this column has a point of contraflexure at the center, each half can be solved as a column with an end moment at one end and a pin at the other. The equations of the previous case then apply using one half of the length for l. The interaction curve for the limit of the elastic range is again a straight line and is plotted on Fig. 9, again for the same column previously used. The curve of instability follows this line very closely for value of P greater than 200 kips. When P is between 200 and 130 kips there is a strain-hardening range where the column is stable. When P is 130 kips and M_A is 851 in. kips the maximum moment is 919 in. kips and the maximum unit stress in the flange is 44 kips per square inch. Here again local buckling is likely to occur. For loads less than 130 kips the column as a whole is stable for large values of M_A and here failure would be caused by local buckling of the flange. As in the previous case, computing the maximum flange stress indicates at approximately what loads local buckling is likely to cause failure.

COLUMN SUBJECTED TO END MOMENT AT TOP, FIXED AT BOTTOM

Equations 57 to 64 also can be used for this case. The expression for determining x_0 is

$$M_0\left(\cos\frac{x_0}{k}\cos\frac{l-x_0}{j}-\frac{k}{j}\sin\frac{x_0}{k}\sin\frac{l-x_0}{j}-\frac{j}{l}\times\right.$$
$$\left.\cos\frac{x_0}{k}\sin\frac{l-x_0}{j}-\frac{k}{l}\sin\frac{x_0}{k}\cos\frac{l-x_0}{j}\right)+$$
$$M_A\left(\frac{k}{l}\sin\frac{x_0}{k}-\cos\frac{l-x_0}{j}+\frac{j}{l}\sin\frac{l-x_0}{j}\right)-$$
$$Pm\left(1-\cos\frac{x_0}{k}\right)\left(\cos\frac{l-x_0}{j}-\frac{j}{l}\sin\frac{l-x_0}{j}\right)=0 \qquad (69)$$

The fixed end moment is obtained by equating the slope to zero at the fixed end

$$M_B=\frac{M_0-M_A\frac{j}{l}\sin\frac{l-x_0}{j}}{\cos\frac{l-x_0}{j}-\frac{j}{l}\sin\frac{l-x_0}{j}} \qquad (70)$$

Values of c_1 and c_2 are

$$c_1=\frac{-M_0+M_A\cos\frac{x_0}{k}-Pm\left(1-\cos\frac{x_0}{k}\right)}{P\sin\frac{x_0}{k}} \qquad (71)$$

$$c_2=-\frac{M_B}{P}\tan\frac{l}{j}+(M_A-M_B)\frac{j}{Pl} \qquad (72)$$

The column used previously was again used to study this case. The interaction curve for yield point stress

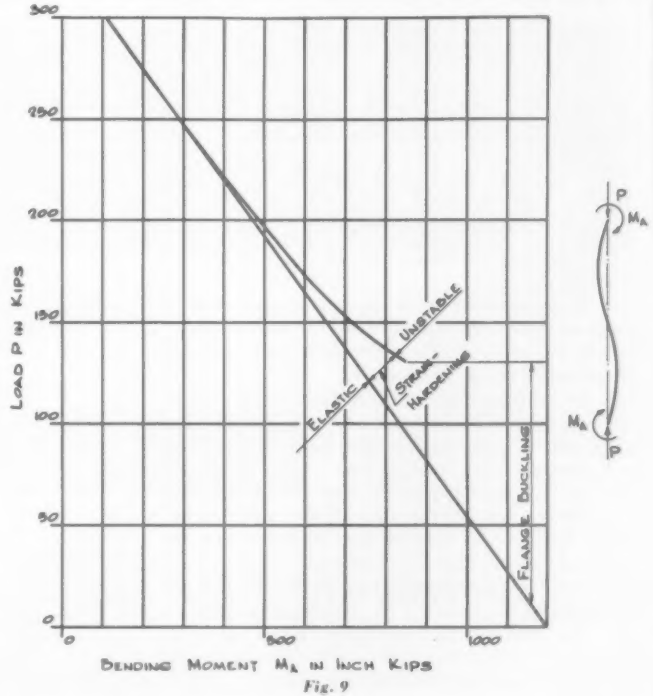

Fig. 9

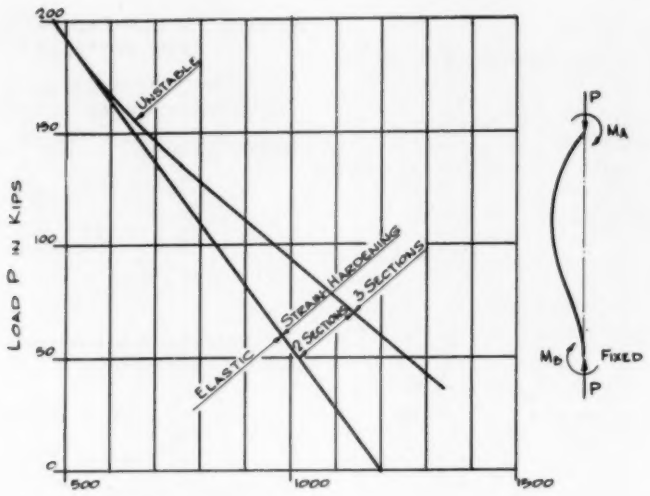

Fig. 10

is as before a straight line. For a load, P, above 200 kips the strain-hardening range is so small that instability occurs practically at the limit of the elastic range. For smaller loads there is some width to the strain-hardening range as shown on Fig. 10. For loads below 150 kips it was found that M_B became so large that the lower end of the column entered the strain-hardening range, and an analysis should then be made dividing the column into 3 sections. Equations for a 3-section analysis have been developed, but the importance of this case does not appear to warrant the large amount of numerical work involved and it is not presented here.

CONCLUSIONS

The following conclusions can be drawn from the foregoing:

1. In columns where the maximum stress in the elastic range is in the central region, the external loads causing this stress to reach the yield point are the maximum the column can support.

2. In columns where the maximum stress in the elastic range is at the end, and particularly where the direct load is small, loads larger than those causing yield point stress can be supported.

3. In such cases the column may fail by buckling as a whole or by local buckling of the more heavily loaded flange. The method here presented can be used to determine which of these types of failure first occurs and the approximate values of the external loads causing failure.

4. The analysis can be applied with a degree of approximation to an actual H column where the bending moment is applied about the strong axis.

5. Conclusions 1 and 2 apply as well to shapes other than H sections, still assuming, of course, the idealized stress-strain relation.

NOTATION

B, C = constants relating to the properties of steel in the strain-hardening range.
E = modulus of elasticity of steel.
F = area of one-column flange.
I = moment of inertia of column cross section.
P_e = column load according to the Euler formula.
P = column load.
P_y = column load for average stress equal to yield point.
M = bending moment at any point.
M_A = bending moment at one end of column.
M_B = bending moment at other end of column.
M_0 = bending moment at limit of elastic section.
M_{ℓ} = bending moment at center of the column.
$c_1c_2c_3$ = constants of integration.
d = distance between column flanges.
j = constant for elastic portion of column.
k = constant for portion of column in strain-hardening range.
l = length of column.
m = constant for portion of column in strain-hardening range.
x = coordinate along length of column.
x_0 = coordinate of point at the limit of the elastic range.
y = deflection at any point on column.
y_{ℓ} = deflection at center of column.
ϵ = unit strain.
ϵ_L = unit strain on left flange.
ϵ_R = unit strain on right flange.
σ = unit stress.
σ_R = unit stress on right flange.
σ_L = unit stress on left flange.
σ_y = unit stress at yield point.

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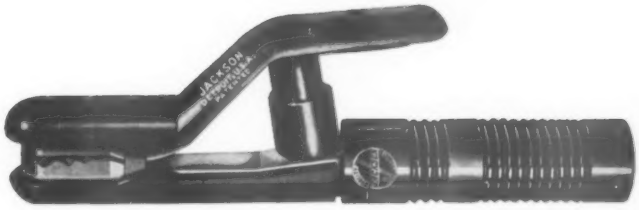

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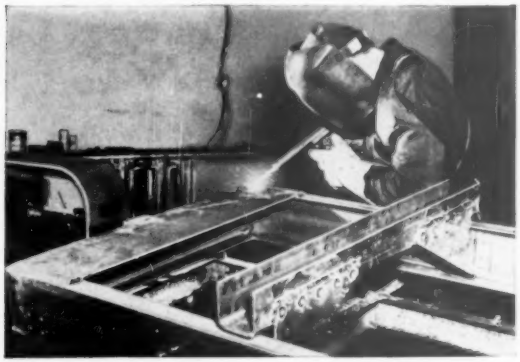

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